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METHOD OF PROPORTIONING CONCRETE MATERIALS—SCREENED AND UNSCREENED GRAVEL

BY
R. W. CRUM

BULLETIN 60

ENGINEERING EXPERIMENT STATION
AMES, IOWA

Published weekly by Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa. Entered as second-class matter, and accepted for mailing at special rate of postage provided for in Section 429, P. L. & R., Act August 24, 1912, authorized April 12, 1920

Monograph

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For all people of the State in the solution of the engineering problems of urban and rural life.

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ENGINEERING EXPERIMENT STATION

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Various standard works have been consulted in preparing the bulletin, notably "Concrete, Plain and Reinforced," by Taylor and Thompson, and Johnson's "Materials of Construction."

SHOWING WEDGING EFFECT OF CEMENT AND WATER ON AGGREGATE.

METHOD OF PROPORTIONING CONCRETE MATERIALS—SCREENED AND UNSCREENED GRAVEL

INTRODUCTION

Thru years of practice it has become customary to specify for concrete mixtures, proportions containing approximately twice as much coarse aggregate as sand, and experience has demonstrated that satisfactory concrete can be thus produced. However, investigation of the material resources of Iowa discloses the fact that a large part of the state must depend upon gravel for concrete aggregates, and that the deposits of gravel invariably contain considerably more sand than coarse pebbles. It would seem therefore, that in order to use Iowa materials to the best advantage, engineers should develope proper methods for making concrete from mixtures containing more of the finer material than has heretofore been customary.

The investigations reported in this bulletin were planned and executed for the purpose of developing proper methods for the use of Iowa gravel containing an excess of sand. Such a method was derived from a study of the data and is presented in this bulletin. The method has been corroborated by other laboratories and has been applied in practice on a large scale with satisfactory results. In so far as to whether or not the sand and coarse pebbles are separated by screening and remixing, or used as pit-run gravel is immaterial with respect to the theory involved. Pit-run gravel is, of course, variable in composition and if it is used the proportion of cement will need to be changed frequently. This is not an insuperable obstacle to its use. It is often merely a matter of adequate inspection. There are two cases in which the use of pit-run gravel is feasible and logical.

(a) Small jobs in which the amount of material involved is small. In this case uniform mixtures can be secured by a reasonable expenditure of effort There is an immense amount of work every year in this class.

(b) Large jobs upon which stock piles containing more than 1000 cubic yards can be accumulated. Handling the gravel from and to such stock piles tends to unify the mass.

In either case constant inspection and change in proportions when needed is essential to satisfactory results. However, the details of inspection are simple and can be performed with little training or effort.

In comparing screened and unscreened material it should be borne in mind that the advantage in screening is lost unless the dividing line between fine and coarse aggregate is accurately defined and maintained within narrow limits.

I. SYNOPSIS OF THE PROCESS OF MAKING CONCRETE

The making of concrete is essentially a manufacturing process, but it suffers under the handicap of having no fixed plant location since the concrete must usually be made at the site of the structure. It is furthermore a chemical as well as a mechanical process, and is subject to various disturbing influences on that account.

The factor that has had the most to do with the growth of the concrete industry and also with its slowness of scientific development has been the fact that anyone could take some cement, water, sand and stone, mix them together and get a substance that would set and harden. The job was so easy, it took a long time to establish the fact that most concrete so made was a very inferior article. That so much successful concrete work has been done in spite of poor methods is evidence of the value of the material. The basic requirements for the manufacture of concrete are today well established, and failure to make at least sound concrete is inexcusable.

The factors upon which the quality of concrete depends are:

1. The raw materials.
2. The mixture or proportions of the materials.
3. The manufacturing operation or fabrication.

It is necessary that materials be selected not only for general quality but for their suitability for the class of concrete contemplated. Material good in quality and suitable for heavy mass concrete might be entirely unsuited for the construction of concrete pavement.

For successul work the raw materials must be properly proportioned. By varying the amounts of the various materials it is possible to make concretes of a wide range of strength. It should always be made as strong as the conditions require, but additional strength is not necessary. **When concrete of low strength is permissible, it is not good practice to allow the use of inferior materials. Good materials should be used and the saving made by using less cement.**

The actual operations in making concrete consist in measuring, mixing, placing, and curing the product and it is needless to say that it is vitally important that these operations be correctly performed. Good materials properly proportioned, are often ruined in the handling, and, the best manufacturing conditions will not make up for poor material or wrong mixtures.

MATERIALS

Cement. The cement is now the most reliable article entering into concrete. The established brands are uniform and reliable and regularly pass the "standard specifications." Such an excellence of product is only secured and maintained by constant vigilance on the part of the plant chemist, and it is not outside the realm of possibility even today that a system may at times fall down in some detail, and an inferior batch of cement result. Cement testing is not a costly process, and it

gives a proper insurance to both the maker and the consumer. All cement should be tested when received. On all work of any importance it should be specified that "the cement to be used shall meet the requirements of the standard specifications for Portland cement of the American Society for Testing Materials."

Water. The water used in mixing should be free from oil, alkali or organic matter.

Aggregates. The aggregate, or total inert material used with water and cement to make concrete, is usually divided into fine aggregate and coarse aggregate.

A generalization as to recommendations for concrete aggregates as made by the * Joint Committee on Concrete is as follows:

"**Fine Aggregate** shall consist of sand, stone screenings or other inert materials with similar characteristics, or of a combination thereof, having clean, hard, strong, durable, uncoated grains and free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam or other deleterious substances.

"Fine aggregate shall range in size from fine to coarse, preferably within the following limits:

Passing thru No. 4 sieve.....not less than 95 percent
Passing thru No. 50 sieve.....not more than 30 percent
Weight removed by decantation.....not more than 3 percent

"Fine aggregate shall preferably be of such a quality that mortar briquettes, cylinders or prisms, consisting of one part by weight of Portland cement and three parts by weight of fine aggregate, mixed and tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement will show a tensile or compressive strength at ages of 7 and 28 days not less than that of 1:3 standard Ottawa sand mortar of the same plasticity made with the same cement. However, fine aggregate which fails to meet this requirement may be used, provided the proportions of cement, fine aggregate, coarse aggregate and water are such as to produce concrete of the strength specified. In testing aggregate, care should be exercised to avoid the removal of any coating on the grains which may effect the strength. Natural sand should not be dried before being made into mortar, but should test stronger in tension in the 1:3 proportion than Ottawa sand. be determined on a separate sample and the weight of the sand used in the test corrected for the moisture content."

Since the Ottawa sand is not a dense mixture, first class natural sand should test stronger intension in the 1:3 proportion than Ottawa sand.

The strength test is not an absolute criterion of the concrete making quality of sand. Its value is rather comparative. It has been shown by Professor Duff A. Abrams that sands of low mortar strength are often

* Joint Committee on Concrete and Reinforced Concrete. American Society Civil Engineers, American Society for Testing Materials, American Railway Engineers Association, Portland Cement Association and American Concrete Institute, June 4, 1921.

suitable for use in concrete when mixed with the proper amount of coarse aggregate and cement. In general, a low strength test is due, either to injurious impurities or to poor grading of the particles. In the first case it should not be used. In the second case it may often be used if the concrete mixture is properly proportioned. On the other hand, sands giving a high mortar strength are often unsuitable for some particular use on account of the presence of soft particles of stone, shale, iron oxide, and similar substances.

The significant factors with respect to the quality of sand for use in concrete are as follows:

(1) Character and texture of grains.
(2) Amount and kinds of impurities present.
    a. Finely divided clay.
    b. Lumps of clay.
    c. Coating on sand grains.
    d. Organic silt.
(3) Size of particles.

The grains of sand should preferably be of siliceous material, particularly for use in a wearing surface.

Particles of mica, iron oxide, and shale are not hard and durable. Mica is usually classed as an injurious impurity. Shale particles are very injurious in that hydration tends to make them expand and rupture the concrete, especially when near the surface.

Some sands resulting from the decomposition of sand stones are not durable. Their quality depends upon the cementing material of the original stone, since a high percentage of the sand grains themselves are composed of yet smaller grains cemented together. The cementing materials in the order of durability are as follows: silica, calcium carbonate, iron oxide, and clay. The latter, especially, does not provide a very durable sand for the manufacture of concrete.

A microscopic examination will give one familiar with such work a good idea of the quality of sand grains. Limestone can be detected by treating the sand with a weak solution of hydrochloric acid. If lime is present it will effervesce. The best method of determining the value of sand is by actual strength tests of the mortar made from the material, except that other determinations must be made of the wearing value, and all other factors must be taken into account.

Impurities. In general the only safe procedure to follow in writing specifications for sand is to specify clean material, although the effect of the impurities may or may not be injurious, depending on the character of the silt and the amount of cement in the mixture.

The effect of finely divided clay or other chemically inert substances is to increase the strength of lean mixtures and to decrease the strength of rich mixtures. The action is purely mechanical and is due to the void filling properties of the clay. For a dense mixture a certain amount of fine material is necessary, and considering density only it is immaterial

what this fine material is, if it is not chemically injurious. Therefore, finely divided clay in lean mixtures in which there is not enough cement to satisfy the mechanical condition of maximum density will be a benefit. On the other hand, in rich mixtures in which there is cement enough for the density consideration, clay would be detrimental.

The difficulty with allowing the use of material containing clay is the uncertainty as to its real quality. Without laboratory facilities and very frequent analyses, it is not safe to use such material. The certainty of high quality and uniformity of product resulting from the use of clean material will more than compensate for the extra amount of cement occasionally needed to make a dense mixture. Lumps of clay or shale in any appreciable amount, render a sand or gravel unfit for use in concrete. A coating of clay or other impurities upon the sand or stone particles prevents adhesion between the cement and aggregates. Organic silt in very small amounts may interfere with the chemical action and cause ultimate disintegration of the concrete.

It will be seen from this discussion that knowledge of the total amount of impurities is insufficient in judging of the effect of the impurities upon the quality of the sand or gravel. The best, and in the end, the cheapest method of testing for this effect is to make the strength test on the material, as recommended in the quotation from the report of the Joint Committee. This will, of course, tell whether the sand is fit for use or not.

In the event that the strength test is not satisfactory, it becomes desirable to ascertain the reason. The presence of limestone, shale, clay or other soft particles may be detected with the aid of a microscope. Treating the sand with a dilute solution of hydrochloric or muriatic acid will cause limestone particles to effervesce. Treating the sand with a 3 percent solution of sodium hydroxide will detect the presence of organic matter. If organic matter is present, it will form a reddish colored solution with the sodium hydroxide. If no organic matter is present the liquid will be colorless or light yellow. Dangerous amounts of organic matter are shown by dark colored solutions ranging from dark red to black.

The effect of the size of particles or grading of aggregate is more a matter of proportioning cement to aggregate than of determining suitability for use. It is possible, with aggregates graded in size from the finest to the coarsest particles, according to recognized standards, to make a much stronger and more impermeable concrete than with aggregate not so graded.

"Coarse aggregate* shall consist of crushed stone, gravel, or other approved inert materials with similar characteristics, or combinations thereof, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter."

* Joint Committee on Concrete recommendations.

The quality of coarse aggregate depends upon the same factors as does the fine aggregate, namely: character and texture of particles, amount and character of impurities, and grading of particles. The quality of coarse aggregate may be better inspected by a visual examination than that of the fine material. The quality of the stone is usually apparent to an inspector familiar with the different rocks (and no other should attempt to judge such material) and the presence of much dirt is also easily detected. The coarse aggregate is best when uniformly graded in size from the finest to the coarsest particles. A sieve analysis is usually necessary to decide the quality from this standpoint. In gravels the principal defects are usually shale pebbles, soft particles, and masses of finer grains loosely cemented together. In crushed stone, the defects are usually excessive crusher dust, flat or elongated particles and foreign material such as clay, shale or dirt. The stones which crush into cubical fragments are to be preferred to those which crush into flakes.

The following extracts from the Specifications for Concrete Road Construction of the Iowa Highway Commission, illustrate requirements for high class material.

Fine aggregate shall be a natural sand consisting of particles of durable rock. It shall be clean within the limits herein prescribed and free from particles of mica, shale, disintegrated granite and other deleterious substances. It shall be considered to be free from organic impurities if the solution, formed by treating the sand with a diluted solution of sodium hydroxide (NaOH) according to the method herein prescribed, is colorless, or is of a light yellowish color.

"Fill a twelve (12) ounce graduated prescription bottle to the four and one-half (4½) ounce mark with the sand to be tested. Add a three (3) percent solution of sodium hydroxide until the volume of sand and solution after shaking amounts to seven (7) ounces. Shake thoroughly and let stand for twenty-four (24) hours. Observe the color of the clear liquid above the sand."

The fine aggregate shall be reasonably well graded from coarse to fine, and not to exceed five (5) percent shall be retained on the sieve having .185 inch square openings. Not to exceed five (5) percent shall pass the one-hundred-mesh sieve.

It shall contain not more than two and one-half (2½) percent of clay by actual dry weight.

Mortar composed of one part by weight of Portland cement and three parts by weight of sand, mixed and tested in accordance with the methods referred to in U. S. Bureau of Standards, Circular No. 33, shall have a tensible strength at the age of 7 and 28 days of not less than one hundred (100) percent of that developed by mortar of the same proportions and consistency made of the same cement and standard Ottawa sand.

The coarse aggregate for Type A (one course) concrete pavement shall conform to the requirements for one of the three following classes:

CLASS ONE. Class one coarse aggregate shall consist of clean, sound, crushed trap rock, quartzite or granite. This class of aggregate shall not contain more than fifteen (15) percent of limestone, sandstone or other similar soft material. Such limestone, sandstone or other material shall have a French coefficient of wear of not less than eight (8).

CLASS TWO. Class two coarse aggregate shall consist of screened and washed gravel or pebbles. It may contain a quantity of material obtained from crushing the oversized stone found in the deposit. Any limestone, sandstone or other material

contained in this class of aggregate shall have a French coefficient of wear of not less than seven (7).

CLASS THREE. Class three coarse aggregate shall consist of material crushed from clean, sound limestone having an average French coefficient of wear of not less than seven (7). It shall be of fairly uniform quality and shall not contain more than five (5) percent of material having a French coefficient of wear as low as five (5). Stone shall be considered to have met this specification if the average of the tests made shows a French coefficient of seven (7) or more and no individual tests show a French coefficient of less than six (6).

In any of the three classes of coarse aggregate the soft or partially disintegrated particles shall not exceed two and one-half (2½) percent. The coarse aggregate shall contain no slate, coal or other materials which easily disintegrate, and shall be free from frozen lumps, sticks, flat and elongated pebbles and vegetable or other deleterious matter. The coarse aggregate may contain not more than five-tenths (5/10) percent of shale pebbles, if in the opinion of the engineer such pebbles are not of an especially injurious nature. When tested by means of laboratory screens, the coarse aggregate shall meet the following requirements:

Passing a screen with 2½ in. openings	100%
Passing a screen with 1½ in. openings	70 to 100%
Passing a screen with ¾ in. openings	30 to 60%
Retained on a screen with .185 in. openings	95%

Unscreened gravel for use as conbined fine and coarse aggregates for Type A or Type B concrete pavement shall consist of clean, sound particles. That portion of the unscreened gravel passing a sieve having .185 in. square openings shall conform to the requirements for fine aggregate in clause D-3 (the first clause of this extract). That portion of the unscreened gravel retained on the .185 in. square opening sieve shall conform to the requirements for class two coarse aggregate.

Coarse aggregate for Type B concrete pavement, except the wearing course of abrasion resisting stone, shall meet the requirement for coarse aggregate for Type A concrete pavement, excepting that a source of supply of crushed stone not meeting the requirement as to French coefficient of wear may be approved providing it meets the following conditions: Concrete specimens made from a representative sample of the probable output of the quarry, selected by a representative of the State Highway Commission, when mixed with cement and a well graded natural sand, in the proportion of 1:2:4 by weight shall develop an average crushing strength at the age of 28 days of 2,500 pounds per square inch. Tests will be made in accordance with the American Society for Testing Materials, tentative standard method for "Making and Storing Specimens of Concrete in the Field" No. C31-20T.

Coarse aggregate for the wearing course of Type B concrete pavement shall consist of clean, sound crushed trap rock, quartzite, granite, or gravel pebbles. This aggregate shall contain not more than fifteen (15) percent of limestone, sandstone or other similar soft material. Such limestone, sandstone, or soft material shall have a French coefficient of wear of not less than eight (8). The soft or partially disintegrated particles shall not exceed two and one-half (2½) percent. It shall contain no slate, shale, coal or other materials which easily disintegrate, and shall be free from frozen lumps, sticks, flat and elongated pebbles, and vegetable or other deleterious matter. It shall pass, when dry, a screen having two and one-half (2½) inch openings, and not more than ten (10) percent shall pass an opening of one (1) inch.

II. THEORY OF PROPORTIONING CONCRETE MIXTURES

Fundamentally the strength of concrete must depend upon two factors; the amount of solid material in a given volume, and the degree to which the solid particles are cemented together.

If with a given aggregate each particle is coated with a film of cement, and then the spaces between the grains filled with cement paste, a concrete of maximum density would result. If some of the cement paste filling in the spaces could be replaced with stone particles harder than cement, concrete of about the same density but stronger would be obtained. Carrying this line of reasoning to a logical conclusion, eventually a mixture very similar to a natural sandstone or conglomerate and probably as strong would be reached. This condition cannot be attained in practice, and the problem is therefore to approach it as nearly as possible by proportioning the available materials to the best advantages.

It is the necessity of mixing the materials with water that makes this problem indeterminate of solution. If dry cement were to be used to fill in the spaces between the particles of aggregate, it might be possible to determine the volume of this void space and add thereto an equal volume of cement by carefully sifting and shaking it into place, but it is not possible to so fill these voids with a paste of cement and water. The film formed on the surface of the grains wedges them apart and thus increases the void space an indeterminate amount. Hence, a determination of the percentage of voids in an aggregate is not a criterion of the amount of cement needed to give a concrete of maximum strength.

Rule for Proportioning. No exact rule can be formulated for making a mixture of maximum strength. However, taking into account the factors which effect the strength and density, a working rule can be formulated which will assure concrete adequate for the work it must do. The application of such a rule will depend largely upon experience and experimental research. Such a rule for proportioning concrete is as follows:

Use the best graded aggregate available, with enough cement to yield concrete of the desired quality, and mix with the least amount of water which will give a workable mixture for the condition under which the concrete must be placed. The fundamental laws upon which this rule depends are these:

1. The strength of the concrete depends upon the amount of solid material present in a unit volume.

2. The strength of concrete depends upon the extent to which the particles of solid material are cemented together.

The amount of solid material in a volume depends primarily upon the grading of the aggregate and upon the amount of water used in mixing. The cementing value depends upon the amount of cement and water and upon the surface area of the particles to be cemented together. The surface area is of course a function of the grading of the aggregate. To state the laws more simply: The quality of concrete depends upon the amount of cement, the amount of mixing water, and the grading of the aggregate.

Water. Too much emphasis cannot be put upon the effect of the amount of the mixing water. The strength is vitally dependent upon the

amount of mixing water. Denser mixtures can be made from a well graded aggregate than from one not so well graded, because a given consistency can be secured with less water. No advantage accrues from using well graded aggregate unless advantage is taken of the fact that such aggregate can be mixed with less water. An excess of water will even cause a very rapid decrease in strength of concrete made from well graded material.

The function of the water in mixing concrete is two-fold; first it provides moisture for the chemical reactions, second, it lubricates the mass so that it can be handled and placed. The water used for lubrication eventually evaporates leaving voids which, of course, reduce the strength. Other voids occur from failure to pack the material into the least possible space. If the void space, due to evaporation can be decreased by using less water, and the same degree of compactness attained, the strength will undoubtedly be increased. It is found, however, that when using concrete of such dryness that tamping is necessary to secure this compactness, the void space due to poor packing increases as fast or faster than the voids are decreased by using less water. Therefore, a limit is reached somewhere beyond which the strength cannot be increased by using less mixing water. Hence the rule "Use as little water in mixing as will yield a workable mixture." The advantage of well graded material here becomes apparent from the fact that this workable mixture can be secured with less water.

What constitutes the dryest workable mixture for a given class of work should be decided in advance and made a part of the specifications. The consistency will necessarily vary for different kinds of work; a paving base may be made much dryer than a reinforced beam. The beam will need more cement to compensate for the additional water.

Consistency Specifications. The consistency may be specified if some means of identification be provided, and the requirement rigidly enforced. Or the exact amount of water may be specified in the proportions as well as the amounts of cement and aggregate. The practical application of such a proportion will require the engineer in charge to make frequent determinations of the amount of water held in the piles of aggregate and correct the volumes of water and aggregate going into the mixture. This proceedure is entirely practicable and scientific, the only difficulty being that the amount of water to yield the proper consistency can seldom be determined in advance of starting operations. When the mixer is started the consistency can be established, the proper volume of water determined and subsequent control will be a simple matter of routine. This method, of course, does not apply if the grading of the aggregate is not uniform. When variable aggregates are used, a superintendent is needed who knows what proper consistency (dryest workable mixture) is and how to get it.

A method of measuring consistency by noting the amount a cylinder or cone of the concrete will slump immediately after being mixed is being

extensively used. The method has given fairly satisfactory results as a means of controlling consistency on the job, but is lacking in exactness as a laboratory measure. A typical specification for consistency is as follows:

There shall be used such an amount of water that the consistency of all the batches of concrete will be the same, the amount of water for each being carefully measured. The consistency shall be such that the concrete will require considerable tamping. There will not be tolerated a consistency that would tend to separate the fine particles from the coarse.

* "The consistency of the concrete shall be determined by the following test:

"A truncated cone, four inches top diameter, eight inches bottom diameter, and twelve inches high, shall be filled with concrete in three layers, approximately four inches in thickness. Each layer shall be puddled by twenty-five to thirty strokes with a 5/8 in. round steel bar twenty-one inches long pointed at the lower end. The cone shall then be removed and the vertical settlement, or "slump," of the concrete noted. The slump shall not exceed one (1) inch when a mechanical finishing machine is to be used and shall not exceed two (2) inches when the finishing is to be done by some other method permitted in the specifications.

"The proper consistency depends on the ratio of fine to coarse aggregate being used, and will be established by the engineer, within the limits prescribed herein."

Well Graded Aggregate. As to what constitutes well graded aggregate, no general rule is available. The only authoritative guide available at present is the recommendation of the Joint Committee on Concrete, that fine aggregate should pass a ¼ inch screen and not more than 30 percent should pass a No. 50 screen, and that coarse aggregate should be uniformly graded from ¼ inch to the maximum size desired. The best relation between fine and coarse aggregate will depend somewhat upon the service for which the concrete is intended. Where strength is the only requirement the volume of coarse aggregate is usually made twice the volume of fine aggregate, as in 1-2-4 for reinforced concrete structures, but where smooth working qualities are important it is usually well to increase the volume of fine aggregate, as in 1-2-3 for concrete pavement. It will be demonstrated in this bulletin that satisfactory concrete can be made from mixtures containing a wide range of ratios of sand to coarse aggregate. It is only necessary to add the proper amount of cement to get the result desired.

The sieve analysis of aggregates affords a means of comparing the concrete making qualities of different materials, as well as methods of combining fine and coarse aggregates. The method of combining fine and coarse materials in certain arbitrary ratios, is not logical, and must be superseded by a scientific method of combining materials to the best advantage.

* Iowa Highway Commission specifications.

The amount of cement to use for a given case should depend upon the quality of the concrete desired and the grading of the aggregate. Under the present system of writing specifications and letting contracts, the character of the aggregate is seldom known at the time of writing the specifications. The custom has become established of making the amount of cement dependent upon the relation between the fine and coarse aggregate, such as one part of cement to 2 parts of sand to 4 parts of crushed stone. For such relations to mean anything, it is necessary that the dividing line between the sand and stone be exact. This dividing size is customarily ¼ inch. The foregoing opinions on the proportioning of concrete mixtures are substantiated by the results of tests reported in this bulletin.

Conclusions. The conclusions with respect to the theory of proportioning, which may be drawn from these tests are these:

1. If the consistency remains the same the strength varies with the coarseness of the aggregate, or, for the same consistency, the finer the aggregate the more cement, (to maintain the strength) is required.
2. The finer the aggregate the more water is required to produce the required consistency.
3. And, therefore, combining 1 and 2, the more water used in mixing, the more cement is required to maintain the strength.

III. PROBLEM AND DESCRIPTION OF INVESTIGATION

The factors upon which the strength of concrete depends are (1) the the density of the concrete, and (2) the extent to which the particles are cemented together. The latter factor depends upon the amount of cement in a given volume, and upon the total surface area of the particles.

Inasmuch as numerous authorities are agreed that the density of the mixture is partly, and the surface area, wholly dependent upon the grading of the aggregate, and that density also depends upon the consistency, or amount of water in the mixture, the writer has formulated the following rule for proportioning concrete mixtures: Use the best graded aggregate available, enough cement to make concrete of the class desired, and mix with the least amount of water which will yield a workable mixture for the conditions under which the concrete is to be placed.

The Problem. The problem considered in this investigation is that of proportioning the mixtures in which there is an excess of fine aggregate, as is true of practically every Iowa pit-run gravel. The results apply to either screened or pit-run gravel.

To establish such a workable relation it is necessary to express the grading of the gravel by numerical functions. Other experimenters, notably Abrams and Edwards, have done so, and their work could be used as a basis for proportioning pit-run materials. However, both Abrams' "Fineness Modulus," and Edwards' "Surface Area" methods require the making of a complete sieve analysis of the material.

The method developed here requires the separation of a sample into two sizes only and a simple determination of the weight per cubic foot of the loose gravel.

The principal conclusion resulting from the investigation is that the grading of pit-run gravel may be measured by the ratio of fine aggregate to total aggregate (that is, percentage of fine aggregate in total) and by the weight per cubic foot of the material, measured loose. For the purpose of commercial convenience the dividing line between fine and coarse aggregate is taken on the common No. 4 sieve. In the following discussion, fine aggregate as defined above will be called "sand" and coarse aggregate "pebbles."

Investigations. Two assumptions have often been made by users in proportioning the cement to pit-run gravels:

1. That the ratio of cement to total aggregate should be a constant, or
2. That the ratio of cement to the sand portion of the aggregate should be a constant.

The former is wrong and on the unsafe side. The latter is also wrong but is on the side of safety, as is shown in Tables I, III and IV.

TABLE I. STRENGTH OF CONCRETE

Ratio of Cement to Total Aggregate a Constant

Percent of "Sand" in Aggregate by Weight	Proportions (1:5)	Density	Water, Percent of Dry Materials	Compressive Strength lb. per sq. in.
42	1:2:3	0.789	9.33	1600
55	1:2¾:2¼	0.770	10.65	1200
75	1:3¾:1¼	0.737	12.65	920
95	1:4¾:¼	0.673	15.30	480

Ratio of Cement to Total Aggregate a Constant. Table I is typical of the strength of concretes made under the assumption that the ratio of cement to total aggregate should be kept constant. Further demonstration of the fallacy of this assumption is not necessary.

Ratio of Cement to Sand a Constant. The assumption that the ratio of cement to sand in the gravel should be constant was investigated in twenty-four series of tests. Materials from several localities and two classes of concrete were studied. Table II gives the physical characteristics of the aggregates used in these investigations.

Each series comprised tests of gravels containing respectively 42, 55, 75, and 95 percent, by weight, of sand. The mixtures were made arbitrarily by combining sand and pebbles in the right amounts. The same sand and pebbles were used in each mixture in a series. Each series included tests of forty specimens. Five specimens were broken for each test of a mixture. Specimens from all series were tested at 28 days old; specimens from some series were tested at 7 days and from others at six months. Specimens were 8 by 16 inch or 6 by 12 inch cylinders stored in water. In some of the series the No. 8 sieve was taken as

TABLE II. PHYSICAL CHARACTERISTICS OF AGGREGATES
Material Used in Specimens Reported in Tables III and IV

Sand No.	Pebbles No.	Percentage of Voids, Loose	Loose Weight lb. per cu. ft.	Percentage of Silt	Specific Gravity	Sieve Analysis: Percent Passing Sieve No.								
						.....	.....	.....	4	8	14	28	48	100
						Size of Opening, in.								
						1.5	0.75	0.371	0.185	0.093	0.046	0.023	0.0116	0.0058
1	..	39.8	99.9	4.0	....	.....	.....	.....	.....	100.0	67.5	25.5	6.5	1.5
2	..	39.3	100.7	2.0	....	.....	.....	.....	.....	100.0	83.5	57.0	18.5	4.5
3	..	42.2	95.9	9.0	....	.....	.....	.....	.....	100.0	72.5	37.0	12.0	7.0
4	..	37.9	103.0	2.0	....	.....	.....	.....	.....	100.0	82.0	49.5	10.0	3.8
5	..	40.5	98.4	4.0	....	.....	.....	.....	100.0	82.0	58.0	23.6	5.8	1.5
6	..	....	.....	1.3	....	.....	.....	.....	100.0	87.0	69.5	45.2	16.0	2.0
7	..	45.0	91.3	7.5	....	.....	.....	.....	100.0	79.8	55.3	28.2	10.0	3.8
8	..	39.7	99.8	0.8	....	.....	.....	.....	100.0	85.2	66.5	39.4	6.2	0.3
11	..	41.2	98.8	2.0	2.68	.....	.....	.....	.....	100.0	87.6	43.2	11.1	1.3
12	..	41.3	101.1	1.8	2.75	.....	.....	.....	100.0	96.4	60.1	32.9	18.2	3.8
13	..	42.0	99.1	1.8	2.73	.....	.....	.....	.....	100.0	76.6	39.3	9.7	1.8
15	..	41.2	98.7	2.0	2.69	.....	.....	.....	100.0	85.2	59.7	31.6	8.6	1.2
16	..	39.3	104.4	1.6	2.75	.....	.....	100.0	92.8	61.5	35.2	17.9	9.7	2.1
17	..	42.3	98.5	1.5	2.72	.....	.....	100.0	98.0	83.9	61.3	30.6	7.4	1.6
20	..	40.0	100.0	2.0	2.68	.....	.....	100.0	99.1	87.7	63.7	33.7	9.1	2.1
21	..	37.7	103.6	...	2.66	.....	.....	100.0	99.4	87.3	59.8	31.5	10.2	2.1
..	9	37.5	103.7	0.0	....	100.0	89.7	52.8	29.6	1.9	.....	.....	.....	.....
..	10	41.6	98.1	0.0	....	100.0	84.5	24.2	3.7	0.8	.....	.....	.....	.....
..	18	42.4	102.3	0.0	2.81	100.0	86.9	49.2	27.9	8.4	.....	.....	.....	.....
..	19	42.4	100.0	0.0	2.82	100.0	74.8	31.7	10.3	.....	.....	.....	.....	.....
..	22	42.2	101.0	1.5	2.80	.....	100.0	82.5	31.5	1.6	.....	.....	.....	.....
..	23	37.4	103.5	1.0	2.65	100.0	64.9	52.5	12.7	1.1	.....	.....	.....	.....

the dividing line between sand and pebbles. The general result was very similar to that obtained when the No. 4 sieve was used.

In Tables III and IV are given the results of these tests showing the variation in strength of concrete with the percentage of sand in the gravel, when the ratio of cement to sand is kept constant. Figs. 5 and 6 show graphically the increase in strength when the cement and sand ratio is a constant.

Testing Methods, Measurement of Materials. All measurements were made by weight.

FIG. 1a — THE CONSISTENCY THRUOUT THE EXPERIMENTS REPORTED HEREIN WAS MAITAINED SO NEARLY AS POSSIBLE BY OBSERVATION AT THE MEDIUM GRADE SHOWN IN THE CENTER PICTURE OF EACH GROUP. Cone test on left, cylinder test on right.

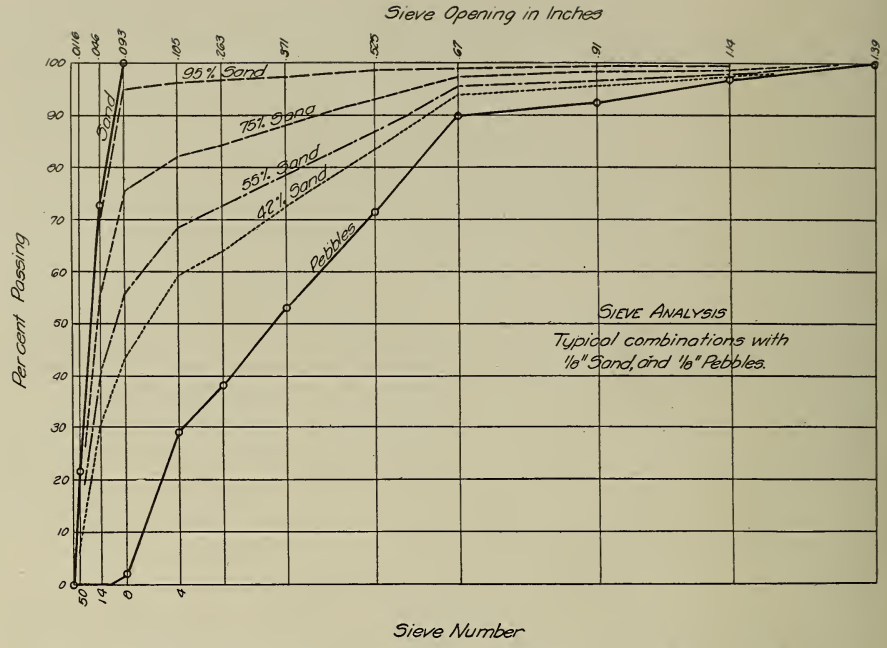


FIG. 1 — TYPICAL SIEVE ANALYSIS DIAGRAMS OF COMBINATIONS OF MATERIALS. Sand passing No. 8 sieve, pebbles retained on No. 8 sieve.

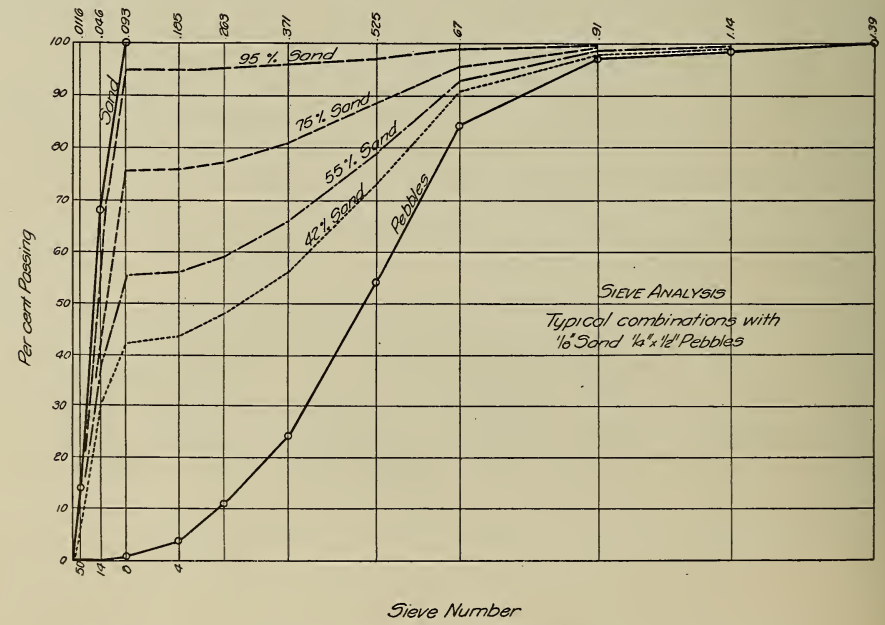


FIG. 2 — TYPICAL SIEVE ANALYSIS DIAGRAMS OF COMBINATIONS OF MATERIALS. Sand passing No. 8 sieve, pebbles retained on No. 4 sieve.

Mixing. Specimens in Series 1 to 22 were mixed in a small Smith mixer. Five specimens were mixed at one time. Series 1a to 16a were mixed by hand in a mortar box. Five specimens were made at one time. Series 25 to 40 were mixed by hand in a mortar box. Five specimens were made at one time. Series 46 and 47 were mixed in a Blystone mixer. Five specimens were made at one time.

Consistency. An attempt was made to bring all specimens to the same degree of plasticity. All were made by the same operator. The consistency adopted may be called medium wet. It is illustrated in figure 1a.

Molding. The specimens were molded in cast iron cylindrical molds, resting on machined plates, without tamping. The concrete was consolidated by puddling with a rod. Before testing the upper ends of the specimens were capped with plaster or rich cement mortar.

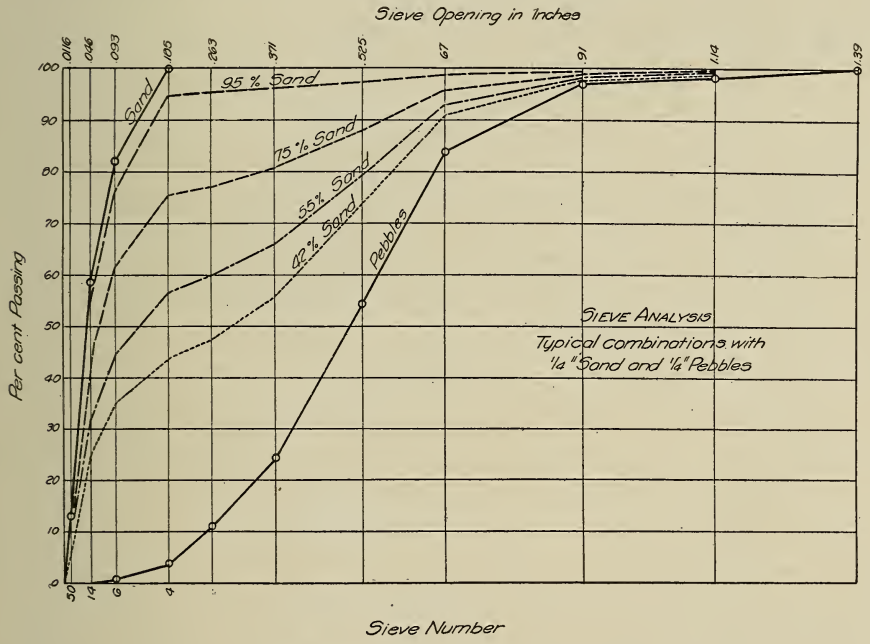


FIG. 3 — TYPICAL SIEVE ANALYSIS DIAGRAMS OF COMBINATIONS OF MATERIALS. Sand passing No. 4 sieve, pebbles retained on No. 4 sieve.

Size of Specimens.

Series 1-22, 8″ in diameter and 16″ long.
″ 1a-16a, 3 out of each batch were 6″ x 12″, and 2 out of each batch were 8″ x 16″, each batch containing 5.
″ 25-40, 6″ x 12″
″ 46-47, 6″ x 12″

Storage. Specimens were stored in water, maintained at room temperature, and removed from water one day before tested.

Testing. All specimens were tested upon a Universal testing machine of 100,000 pounds capacity.

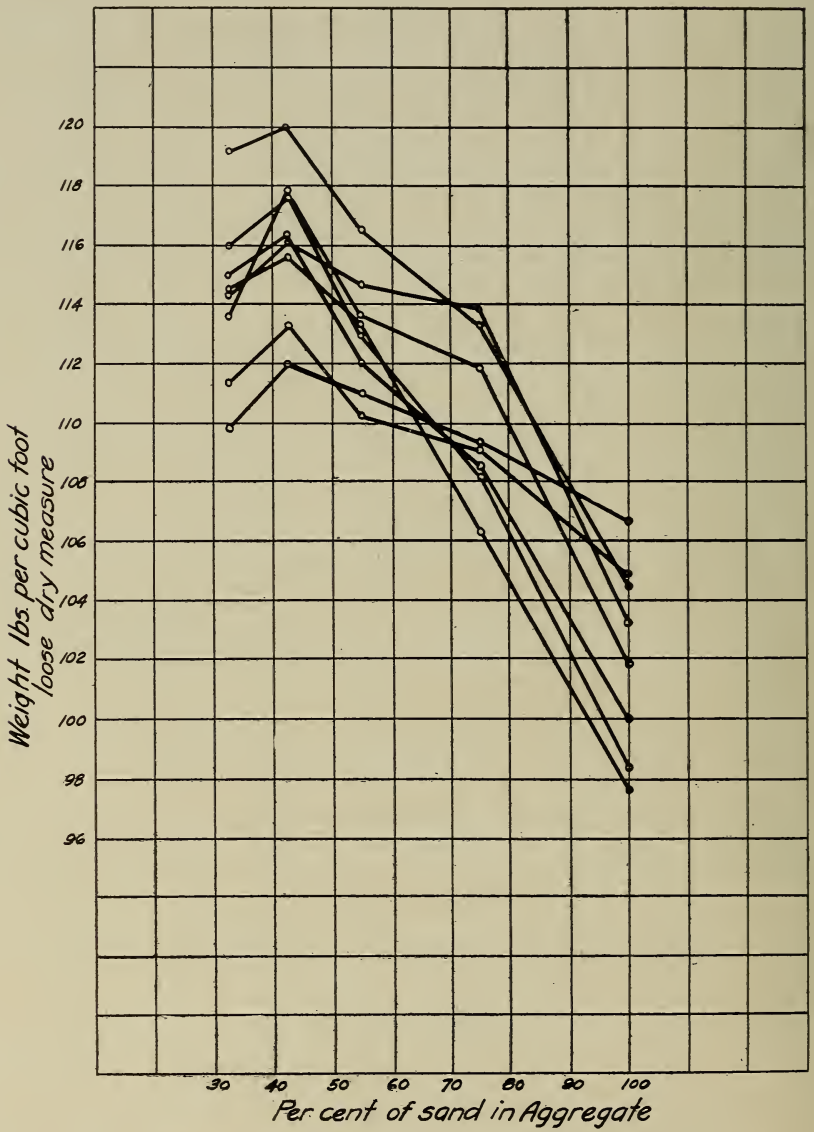


FIG. 4 — SHOWING THE TREND OF VARIATION IN WEIGHT PER CUBIC FOOT OF PIT RUN GRAVEL WITH THE SAND CONTENT OF THE GRAVEL.

Tables of Strength and Data. Each strength value shown in the following tables, and each point shown in the diagrams of strength variation, is the average resulting from five specimens. Series of tests which

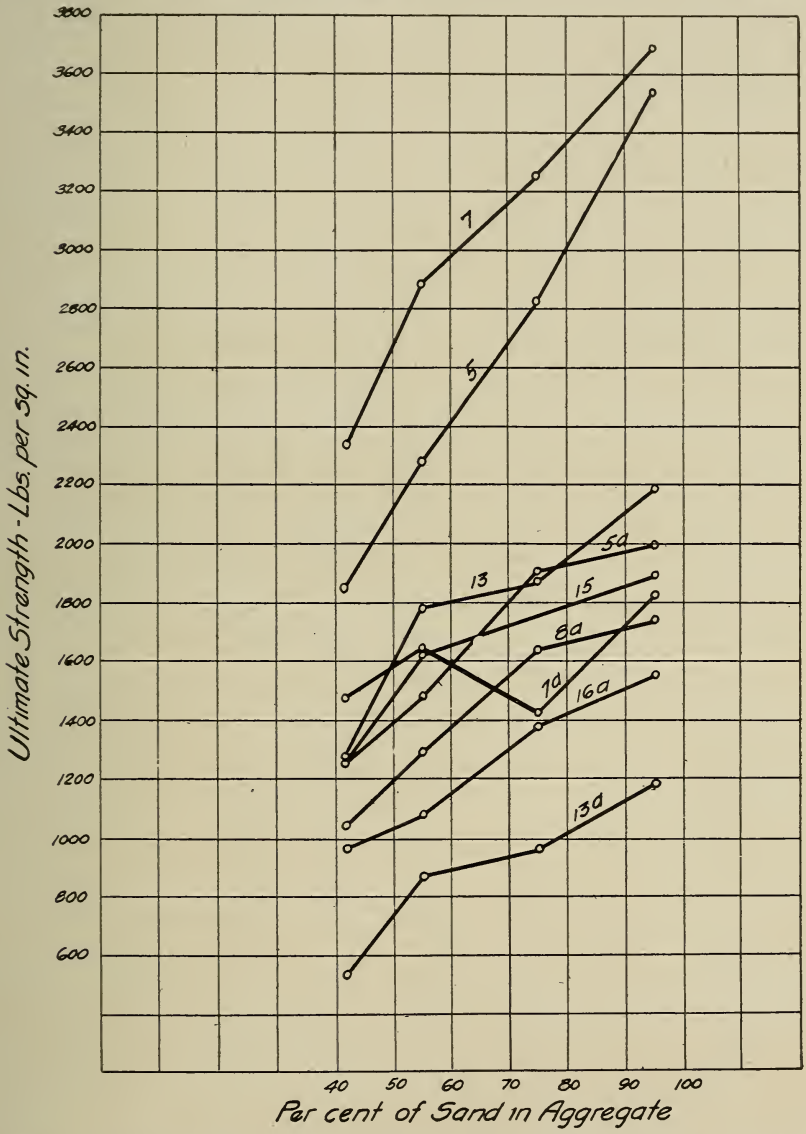


FIG. 5 — Showing that, if the ratio of cement to sand is a constant, the crushing strength increases with the sand content of the gravel plotted from data in tables 3.

are comparable by reason of being made under the same conditions are grouped in the same table.

It will be noted from Tables III and IV that if the ratio of cement to the sand portion of the aggregate is kept constant, the strength of the

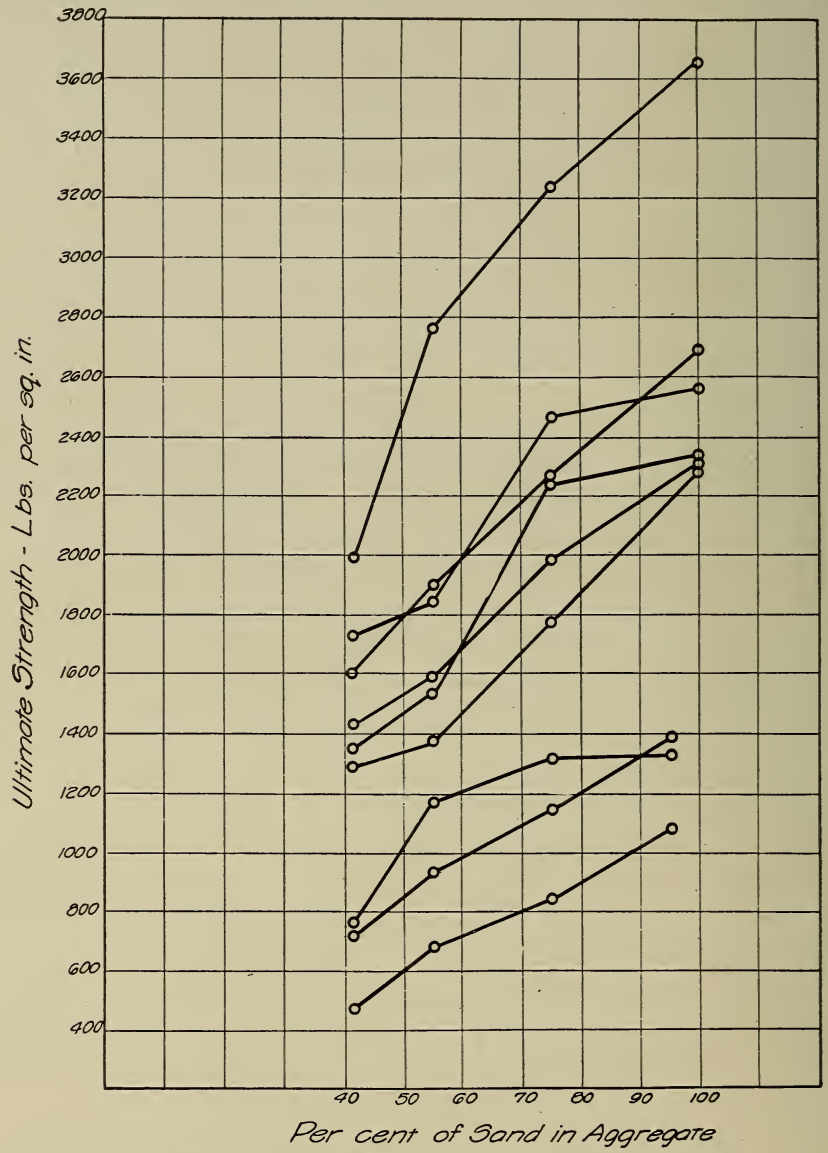


FIG. 6 — Same as 5. Data in table 4.

concrete will increase as the sand content increases. This is of course a safe procedure but it is not good engineering. It is evident that a correct method of proportioning materials, containing varying percentages of sand in the aggregate will call for cement somewhere between the amount required to keep the cement to aggregate ratio constant, and that amount required to keep the cement to sand ratio constant. The amount of cement must increase as the sand content increases but not so rapidly as in the tests shown in Tables III and IV.

The tests shown in Table V were made following a preliminary study of the results obtained in the series shown in Tables III and IV. Further study demonstrated that the method by which they were proportioned was erroneous. However, the data corroborated the conclusions drawn from the other tests as to the factors upon which the strength depends.

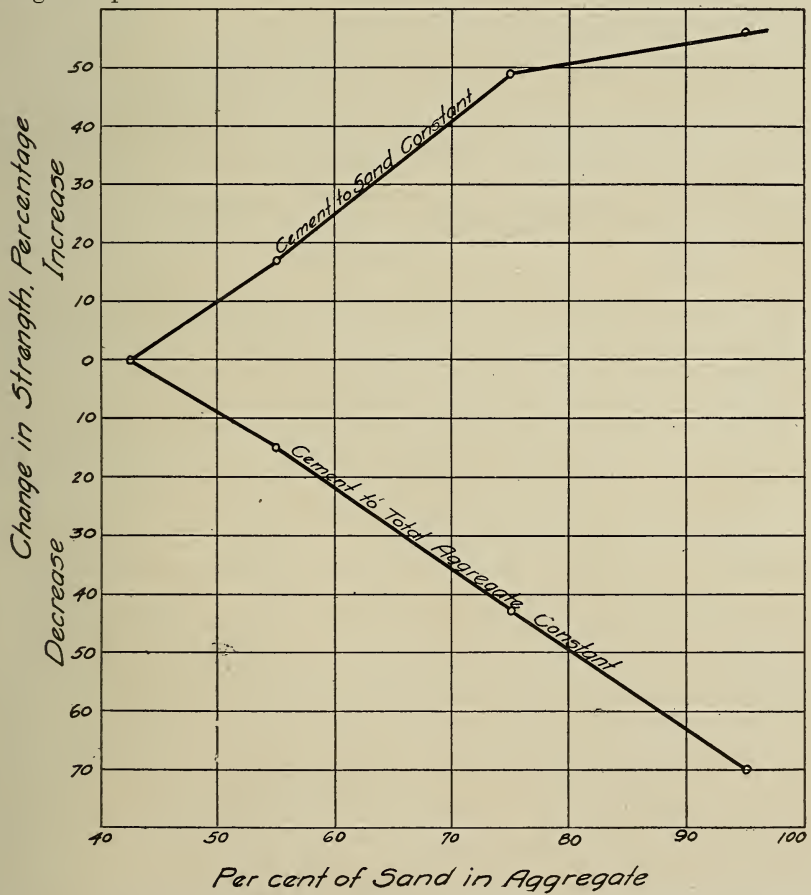


FIG. 8 — THIS DIAGRAM SHOWS THAT AS THE SAND CONTENT OF THE GRAVEL INCREASES, THE STRENGTH INCREASES WHEN THE RATIO OF CEMENT TO TOTAL AGGREGATE IS A CONSTANT. Summation of data in tables 1-3 and 4.

Class I - Sand passing No.4 - Pebbles retained on No 4 and passing 1½"																		
Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Weight: Sand to Pebbles	Loose Volume: Cement to Aggregate	Loose Volume: Sand to Pebbles	Loose Volume: Computed for Equivalent Str.	Absolute Vol.: As Used	Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggreg.	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Volume in Green Con: Cement (c)	Sand (s)	Pebbles (p)	c+s+p = Density	Per Cent Water in Mix. - Weight	Crushing Strength Lbs. per Sq. In: Age 7 Days	Age 28 Das.
5	5	1-4.75	42-58	1-3.9	48-66	1-4.05	1-5.5	1-5.5	112.0	147.6	.121	.284	.379	.784	10.9	1235	1854
		1-3.66	55-45	1-3.2	62-51	1-4.1	1-4.3	1-5.5	110.2	149.0	.148	.346	.292	.786	11.2	1438	2275
		1-2.66	75-25	1-2.3	82-27	1-3.35	1-3.1	1-4.35	107.1	147.2	.182	.426	.142	.750	13.9	1637	2826
		1-2.10	95-5	1-2	97-5	1-3.2	1-2.5	1-3.9	100.1	146.1	.209	.493	.030	.732	14.8	2244	3532
6	6	1-4.75	42-58	1-3.8	48-68	1-3.9	1-5.4	1-5.4	114.8	146.1	.122	.279	.383	.784	9.8	1872	3360
		1-3.66	55-45	1-3.1	62-52	1-3.7	1-4.4	1-5.1	112.35	146.1	.144	.340	.291	.775	10.4	1792	3296
		1-2.66	75-25	1-2.3	80-27	1-2.7	1-3.1	1-3.6	107.1	141.2	.175	.408	.137	.720	13.2	2120	3452
		1-2.10	95-5	1-2	96-52	1-2.7	1-2.5	1-3.35	101.1	141.8	.206	.482	.024	.712	14.5	2360	3864
7	7	1-4.75	42-58	1-3.9	51-66	1-4.15	1-5.6	1-5.6	111.3	146.1	.116	.272	.382	.770	11.85	1150	2340
		1-3.66	55-45	1-3.2	65-49	1-4.05	1-4.25	1-5.3	107.8	145.6	.145	.339	.276	.760	12.1	1423	2872
		1-2.66	75-25	1-2.4	84-26	1-3.3	1-3.1	1-4.1	102.3	143.0	.175	.410	.136	.721	15.0	1550	3245
		1-2.10	95-5	1-2.1	98-46	1-3.35	1-2.5	1-3.8	94.0	142.0	.204	.480	.024	.708	15.3	2045	3680

TABLE III PART 1

Sand Passing No. 8 - Pebbles retained on No.8 and passing 1½"																		
Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Weight: Sand to Pebbles	Loose Volume: Cement to Aggregate	Loose Volume: Sand to Pebbles	Loose Volume: Computed for Equivalent Str.	Absolute Vol.: As Used	Absolute Vol.: Computed for Equiv. Str.	Weight per Cu. Ft.: Aggregat	Weight per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. in Green Concrete: Cement (c)	Sand (s)	Pebbles (p)	c+s+p = Density	Per Cent Water in Mix. - Weight.	Crushing Strength Lbs. per Sq. In: Age 7 Days	Age 28 Days
							CLASS "1."										
2	2	1-4.75	42-58	1-3.8	48-65	1-3.9	1-5.6	1-5.6	116.25	148.5	.120	.283	.388	.791	10.7	1460	1992
		1-3.66	55-45	1-3.0	63.50	1-3.4	1-4.3	1-4.8	114.80	148.3	.147	.346	.284	.777	11.8	1770	2760
		1-2.66	75-25	1-2.3	81-26	1-2.75	1-3.1	1-3.7	109.10	146.0	.178	.419	.140	.737	14.8	1570	3232
		1-2.1	95-5	1-1.9	96-50	1-2.4	2.5	1-3.0	102.10	143.0	.203	.476	.024	.703	17.2	1440	3632
							CLASS "3."										
10	2	1-70	42.58	1-5.7	48.65	1-5.8	1-8.3	1-8.3	116.25	145.2	.083	.291	.400	.774	11.5	720	1348
		1-5.25	55-45	1-4.3	63-50	1-5.7	1-6.4	1-8.0	114.80	146.2	.104	.365	.299	.768	12.4	980	1532
		1-4.0	75-25	1-3.4	81-26	1-4.55	1-4.7	1-6.1	109.10	141.8	.127	.446	.149	.722	15.4	1000	2241
		1-3.17	95-5	1-2.9	96-50	1-4.2	1-3.7	1-5.3	102.10	140.8	.148	.521	.028	.697	17.6	1120	2339

TABLE III PART 2

Class 3 - Sand passing No. 4 - Pebbles retained on No. 4 and passing 1½"

Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Proportions: Weight: Sand to Pebbles	Proportions: Loose Volume: Cement to Aggregate	Proportions: Loose Volume: Sand to Pebbles	Proportions: Loose Volume: Computed for Equivalent Str.	Proportions: Absolute Vol.: As Used	Proportions: Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggreg.	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. in Green Concrete: Cement (c)	Absolute Volume Parts of Unit Vol. in Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol. in Green Concrete: Pebbles (p)	Absolute Volume Parts of Unit Vol. in Green Concrete: c+s+p = Density	Per Cent Water in Mix. - Weight	Crushing Strength Lbs. Per Sq. In.: Age 7 Days	Crushing Strength Lbs. Per Sq. In.: Age 28 Days
13	5	1-7.0	42-58	1-5.9	48-66	1-6.0	1-8.3	1-8.3	112.0	148.2	.086	.300	.413	.799	10.1	690	1274
		1-5.25	55-45	1-4.5	62-51	1-5.4	1-6.2	1-7.3	110.2	147.4	.109	.382	.289	.780	11.6	1065	1779
		1-4.0	75-25	1-3.5	82-27	1-4.7	1-4.8	1-6.2	107.1	145.8	.131	.460	.164	.755	13.3	1520	1870
		1-3.17	95-5	1-3.0	97-5.1	1-4.55	1-3.7	1-5.6	100.1	145.0	.156	.550	.028	.738	15.2	1290	2178
14	6	1-7.0	42-58	1-5.9	48-66	1-6.0	1-8.4	1-8.4	114.8	145.6	.083	.292	.403	.778	11.1	1080	1920
		1-5.25	55-45	1-4.4	62-52	1-5.2	1-6.2	1-7.2	11235	144.0	.105	.368	.280	.753	12.7	1376	2112
		1-4.0	75-25	1-3.6	80-27	1-4.7	1-4.8	1-6.2	1071	142.0	.126	.443	.159	.728	14.2	1400	2376
		1-3.17	95-5	1-2.9	96-52	1-3.95	1-3.7	1-4.9	1011	141.2	.147	.512	.028	.687	17.85	1632	2384
15	7	1-7.0	42-58	1-5.9	51-66	1-6.15	1-8.4	1-8.4	111.3	146.0	.084	.294	.408	.786	10.2	732	1282
		1-5.25	55-45	1-4.6	65-49	1-5.8	1-6.4	1-7.7	107.8	145.8	.105	.367	302	.774	11.0	942	1618
		1-4.0	75-25	1-3.7	84.26	1-5.4	1-4.7	1-6.8	1023	145.1	.133-	465	.155	.753	13.2	908	1289
		1-3.17	95-5	1-3.2	98-46	1-4.8	1-3.7	1-5.5	94.0	141.0	.153	538	.028	.719	14.1	1164	1893

TABLE III PART 3

Class 1 - Sand passing No. 8 - Pebbles retained on No. 4 and passing 1½"

Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Proportions: Weight: Sand to Pebbles	Proportions: Loose Volume: Cement to Aggregate	Proportions: Loose Volume: Sand to Pebbles	Proportions: Loose Volume: Computed for Equivalent Str.	Proportions: Absolute Vol.: As Used	Proportions: Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggregate	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. in Green Concrete: Cement (c)	Absolute Volume Parts of Unit Vol. in Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol. in Green Concrete: Pebbles (p)	Absolute Volume Parts of Unit Vol. in Green Concrete: c+s+p = Density	Per Cent Water in Mix. - Weight	Crushing Strength Lbs. per Sq. In.: Age 7 Days	Crushing Strength Lbs. per Sq. In.: Age 28 Days
17	1	1-4.75	42-58	1-3.9	48-67	1-3.9	1-5.4	1-5.4	113.2	147.2	.121	.283	.372	.776	11.0	1251	2514
		1-3.66	55-45	1-3.1	61-51	1-3.75	1-4.3	1-5.1	110.4	146.7	.144*	.338	.286	.768	12.0	1996	2968
		1-2.66	75-25	1-2.4	79.27	1-3.25	1-3.1	1-4.2	105.5	146.0	.179	.419	.139	.737	14.5	1886	3060
		1-2.1	95-5	1-2	96-5.1	1-3.0	1-2.5	1-3.7	101.1	143.6	.206*	.485	.025	.716	15.3	2430	3652
18	2	1-4.75	42-58	1-3.7	51-72	1-3.7	1-5.5	1-5.5	121.2	147.6	.120	.280	.385	.785	10.85	1704	2560
		1-3.66	55-45	1-2.9	65-54	1-3.5	1-4.3	1-5.05	118.3	144.5	.144	.340	.276	.760	11.7	1424	2496
		1-2.66	75-25	1-2.3	83-28	1-2.8	1-3.1	1-3.8	110.6	144.0	.177	.414	.139	.730	14.6	2404	3252
		1-2.1	95-5	1-2	96-52	1-2.7	1-2.5	1-3.4	102.0	143.0	.204	.482	.024	.710	15.6	2672	3612

TABLE III PART 4

Class 3 - Sand passing No. 8 - Pebbles retained on No. 4 and passing 1½"																		
Series No.	Sand No.	Proportions							Weight per Cu. Ft.		Absolute Volume Parts of Unit Vol. in Green Concrete				Per Cent Water in Mix - Weight	Crushing Strength Lbs. per Sq. In.	
		Weight		Loose Volume			Absolute Vol.										
		Cement to Aggregate	Sand to Pebbles	Cement to Aggregate	Sand to Pebbles	Computed for Equivalent Str.	As Used	Computed for Equivalent Str.	Aggregate	Green Concrete	Cement(c)	Sand (s)	Pebbles(p)	c+s+p = Density		Age 7 Das.	Age 28 Das.
21	1	1-7.0	42-58	1-5.9	48-67	1-6.05	1-8.4	1-8.4	113.2	146.1	.083	.292	.405	.780	11.1	1029	1860
		1-5.25	55-45	1-4.5	61-51	1-5.5	1-6.25	1-7.45	110.4	145.5	.105	.373	.282	.760	12.6	1132	2008
		1-4.0	75-25	1-3.6	79-27	1-5.4	1-4.7	1-7.0	105.3	143.8	.132	.464	.154-	.750	12.6	1343	2044
		1-3.17	95-5	1-2.9	96-5.1	1-4.9	1-3.7	1-6.05	101.1	143.0	.154	.544	.029	.727	14.7	1423	2400
22	2	1-7.0	42-58	1-5.5	51-72	1-5.6	1-8.3	1-8.3	121.2	146.5	.084	.294	.405	.783	10.9	808	1375
		1-5.25	55-45	1-4.2	65-54	1-5.1	1-6.2	1-7.4	118.3	146.1	.106	.375	.264	.765	12.6	1016	1782
		1-4.0	75-25	1-3.5	83-28	1-4.6	1-4.8	1-6.3	110.6	143.6	.128	.451	.161	.740	13.6	976	1592
		1-3.17	95-5	1-2.9	96-52	1-4.8	1-3.7	1-5.05	1020		.149	.524	.028	.701		1112	1975

TABLE III PART 5

Class 1 - Sand passing No. 8 - Pebbles retained on No. 8 and passing 1½"																		
Series No.	Sand No.	Proportion							Weight Per Cu. Ft.		Absolute Volume Parts of Unit Vol. in Green Concrete				Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.	
		Weight		Loose Volume			Absolute Vol.										
		Cement to Aggregate	Sand to Pebbles	Cement to Aggregate	Sand to Pebbles	Computed for Equivalent Str.	As Used	Computed for Equivalent Str.	Aggregate	Green Concrete	Cement(c)	Sand (s)	Pebbles(p)	c+s+p = Density		Age 7 Das.	Age 28 Das.
10	1	1-5.37	42-58	1-4.5	47-63	1-4.5	1-6.2	1-6.2	112.50	144.0	.106	.271	.389	.766	10.65	929	1603
		1-4.20	55-45	1-3.5	62-49	1-4.2	1-4.9	1-5.8	112.35	143.0	.128	.344	.282	.754	11.8	1397	1901
		1-2.87	75-25	1-2.5	81-26	1-3.8	1-3.35	1-5.05	107.85	141.0	.168	.423	.141	.732	13.5	1319	2267
		1-2.15	95-5	1-2.0	96-5	1-3.35	1-2.4	1-4.15	101.10	139.5	.199	.476	.025	.700	15.5	1935	2685
3-a	3	1-5.30	42-58	1-4.5	48-62	1-4.55	1-6.2	1-6.2	110.45	145.0	.106	.277	.382	.765	11.95	1009	1731
		1-4.06	55-45	1-3.5	63-47	1-4.2	1-4.8	1-5.6	108.90	143.0	.129	.340	.279	.748	13.4	1122	1853
		1-2.76	75-25	1-2.5	81-25	1-3.55	1-3.2	1-4.5	103.50	138.0	.169-	.407	.136	.712	14.9	1420	2462
		1-2.05	95-5	1-2.0	96-5	1-3.07	1-2.4	1-3.6	96.40	137.0	.198+	.453	.025	.676	17.1	1441	2552
4-a	4	1-6.08	42-58	1-4.5	52-71	1-4.15	1-6.4	1-6.4	127.0	142.0	.095	.284+	.374	.753	11.7	586	1293
		1-4.55	55-45	1-3.5	65-53	1-4.15	1-5.35	1-6.2	122.2	140.0	.116+	.341	.279	.736	13.2	703	1373
		1-3.05	75-25	1-2.5	84-28	1-3.85	1-3.6	1-5.4	115.0	138.0	.155+	.417	.139	.711	15.5	800	1776
		1-2.24	95-5	1-2.0	97-5	1-3.5	1-2.6	1-4.5	105.2	136.5	.188+	.468	.024	.680	18.0	1038	2280

TABLE IV PART 1

Class 1 - Sand passing No. 4 - Pebbles retained on No. 4 and passing 1½".

Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Proportions: Weight: Sand to Pebbles	Proportions: Loose Volume: Cement to Aggregate	Proportions: Loose Volume: Sand to Pebbles	Proportions: Loose Volume: Computed for Equivalent Str.	Proportions: Absolute Vol.: As Used	Proportions: Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggregate	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. in Green Concrete: Cement (c)	Absolute Volume Parts of Unit Vol. in Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol. in Green Concrete: Pebbles (p)	Absolute Volume Parts of Unit Vol. in Green Concrete: c+s+p = Density	Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.: Age 7 Das.	Crushing Strength Lbs. Per Sq. In.: Age 28 Das.
5-a	5	1-5.36	42-58	1-4.5	48-66	1-4.5	1-6.15	1-6.15	112.0	144.0	.106	.274	.379	.759	11.9	626	1273
		1-4.13	55-45	1-3.5	62-51	1-4.05	1-4.87	1-5.50	110.7	142.0	.126	.338-	.276	.740	12.9	638	1402+
		1-2.85	75-25	1-2.5	82-27	1-3.45	1-3.09	1-4.53	107.1	137.2	.173	.402	.133+	.708	14.8	880	1099
		1-2.13	95-5	1-2.0	97-5	1-2.90	1-2.5	1-3.58	100.1	137.2	.191+	.453-	.024	.668	18.4	928	1984
7-a	7	1-5.34	42-58	1-4.5	51-66	1-4.5	1-6.28	1-6.28	111.3	143.8	.103+	.272	.375	.750	13.0	691	1402
		1-4.01	55-45	1-3.5	65-49	1-4.1	1-4.71	1-5.42	107.8	141.3	.127+	.329	.269	.725	14.65	734	1646
		1-2.75	75-25	1-2.5	84-26	1-3.3	1-3.2	1-4.15	102.3	137.7	.162	.388	.130	.680	17.5	739	1422
		1-2.0	95-5	1-2.0	98-5	1-3.2	1-2.34	1-3.70	94.0	136.0	.197-	.439	.023	.659	19.7	880	1822
6-a	6	1-5.45	42-58	1-4.5	48-67	1-4.56	1-6.38	1-6.38	113.8	144.0	.104	.279-	.385	.768	10.8	381	1052
		1-4.22	55-45	1-3.5	62-52	1-3.7	1-4.92	1-5.16	113.2	140.2	.124	.335	.275-	.734	12.2	458	1287
		1-2.90	75-25	1-2.5	82-28	1-3.4	1-3.4	1-4.52	109.0	141.0	.162	.412	.138	.712	15.0	612	1638
		1-2.17	95-5	1-2.0	97-5	1-2.75	1-2.54	1-3.43	102.0	135.0	.188+	.453	.024	.665	17.0	598	1722

TABLE IV PART 2

Class 3 - Sand passing No. 8 - Pebbles retained on No. 8 and passing 1½"

Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Proportions: Weight: Sand to Pebbles	Proportions: Loose Volume: Cement to Aggregate	Proportions: Loose Volume: Sand to Pebbles	Proportions: Loose Volume: Computed for Equivalent Str.	Proportions: Absolute Vol.: As Used	Proportions: Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggregate	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. in Green Concrete: Cement c	Absolute Volume Parts of Unit Vol. in Green Concrete: Sand s	Absolute Volume Parts of Unit Vol. in Green Concrete: Pebbles p	Absolute Volume Parts of Unit Vol. in Green Concrete: c+s+p = Density	Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.: Age 7 Das.	Crushing Strength Lbs. Per Sq. In.: Age 28 Das.
9-a	1	1-8.40	42-58	1-7	47-63	1-7.1	1-9.8	1-9.8	112.50	145.3	.072	.296	.407	.775	11.7	508	768.
		1-6.00	55-45	1-5	62-49	1-6.2	1-7.0	1-8.55	112.35	143.5	.094	.362	.297	.753	12.9	523	1174
		1-4.57	75-25	1-4	81-26	1-5.6	1-5.33	1-7.37	107.85	140.4	.115	.460	.153	.728	13.35	665	1318
		1-3.22	95-5	1-3	96-5	1-4.9	1-3.8	1-6.1	101.10	136.8	.145	.520	.028	.693	13.45	694	1327
11-a	3	1-8.23	42-58	1-7	48-62	1-7.1	1-9.6	1-9.6	110.45	143.5	.072	.291	4.01	.764	11.7	378	721
		1-5.79	55-45	1-5	63-47	1-6.8	1-6.76	1-9.05	108.90	143.0	.097	.360	.296	.753	12.5	463	937
		1-4.40	75-25	1-4	81-25	1-5.9	1-5.16	1-7.5	103.50	139.8	.117	.453	.151	.721	14.0	616	1153
		1-3.08	95-5.	1-3	96-5	1-5.0	1-3.6	1-5.93	96.40	136.5	.148	.504	.027	.679	16.7	789	1391
12-a	4	1-9.46	42-58	1-7	52-71	1-7.22	1-11.1	1-11.1	127.00	141.7	.062	.290	.400	.752	12.2	228	479
		1-6.50	55-45	1-5	65-55	1-6.46	1-7.65	1-9.6	122.20	138.8	.084	.354	.288	.726	13.3	363	690
		1-4.89	75-25	1-4	84-28	1-6.0	1-5.75	1-8.4	113.00	134.8	.104+	.448	.150	.702	13.3	401	848
		1-3.36	95-5	1-3	97-5	1-5.1	1-3.94	1-6.5	105.20	133.5	.139	.520	.028	.687	13.3	448	1077

TABLE IV PART 3

Class 3 - Sand passing No. 4 - Pebbles retained on No. 4, passing 1½".																		
Series No.	Sand No.	Proportions							Weight Per Cu. Ft.		Absolute Volume Parts of Unit Vol. in Green Concrete				Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.	
		Weight		Loose Volume			Absolute Vol.										
		Cement to Aggregate	Sand to Pebbles	Cement to Aggregate	Sand to Pebbles	Computed for Equivalent Str.	As Used	Computed for Equivalent Str.	Aggregate	Green Concrete	Cement(c)	Sand(s)	Pebbles(p)	c+s+p = Density		Age 7 Days.	Age 28 Days.
13-a	5	1-8.34	42-58	1-7	48-66	1-7.05	1-9.7	1-9.7	112.0	136.5	.069	.281+	.389	.739	10.7	268	541
		1-5.90	55-45	1-5	62-51	1-6.7	1-6.9	1-9.1	110.7	137.0	.092	.349	.286	.727	11.6	402	876
		1-4.56	75-25	1-4	82-27	1-6.1	1-5.35	1-8.05	107.1	138.0	.111+	.446	.148	.705	14.8	328	960
		1-3.19	95-5	1-3	97-5	1-5.7	1-3.76	1-7.0	100.1	135.5	.143	.510	.027	.680	16.3	403	1188
15-a	7	1-8.30	42-58	1-7	51-66	1-7.0	1-9.7	1-9.7	113.3	145.5	.073	.297	.410	.780	11.0	345	967
		1-5.75	55-45	1-5	65-49	1-6.1	1-6.74	1-8.05	107.8	143.0	.097+	.359	.294	.750	12.8	416	1080
		1-4.37	75-25	1-4	84-26	1-5.4	1-5.1	1-6.75	102.3	140.3	.118	.452	.150	.720	14.3	578	1377
		1-3.00	95-25	1-3	98-5	1-4.55	1-3.5	1-5.25	94.0	135.0	.150	.499	.026	.675	16.7	631	1556
16-a	8	1-8.50	42-58	1-7	48-67	1-7.05	1-9.87	1-9.87	113.8	147.7	.074	.307	.423	.804	9.2	413	1136
		1-6.02	55-45	1-5	62-52	1-5.05	1-7.53	1-7.0	113.2	142.0	.088	.364	.298	.750	11.1	460	1216
		1-4.65	75-25	1-4	82-28	1-4.9	1-5.43	1-6.55	109.0	142.5	.115	.469	.156	.740	13.3	437	1190
		1-3.26	95-5	1-3	97-5	1-3.9	1-3.82	1-4.9	102.0	136.0	.143	.520	.027	.690	15.1	604	1336

TABLE IV PART 4

Class 1 - Sand passing No. 8 - Pebbles retained on No. 8 passing 1½"																		
Series No.	Sand No.	Proportions							Weight Per Cu. Ft.		Absolute Volume Part of Unit Vol. of Set Concrete				Per Cent Water in Mix - Weight.	Crushing Strength Lbs. Per Sq. In.	
		Weight		Loose Volume			Absolute Vol.										
		Cement to Aggregate	Sand to Pebbles	Cement to Aggregate	Sand to Pebbles	Computed for Equivalent Str.	As Used	Computed for Equivalent Str.	Aggregate	Green Concrete	Cement(c)	Sand (s)	Pebbles(p)	c+s+p = Density		Age 28 Days.	Age 6 Mos.
25	1	1-6.17	33-67	1-5.1	39.2-74.7	1-4.85	1-6.96	1-6.72	114.25	147.50	.097	.229	.446	.772	9.04	2610	3980
		1-5.54	42-58	1-4.5	51.0-65.5	1-4.5	1-6.23	1-6.23	115.81	146.00	.105	.283	.374	.762	9.76	2650	3620
		1-4.58	55-45	1-3.8	66.0-51.0	1-4.1	1-5.22	1-5.67	113.50	144.50	.120	.352	.275	.747	10.15	2310	3700
		1-3.51	75-25	1-3.1	84.9-26.0	1-3.65	1-4.0	1-4.7	106.25	141.00	.143	.435	.138	.716	12.70	2740	4070
		1-2.70	95-5	1-2.6	95.0-4.6	1-3.55	1-3.14	1-4.2	97.81	139.00	.166	.503	.025	.696	14.30	2860	3960
26	11	1-6.18	33-67	1-5.1	39.0-74.5	1-4.85	1-6.97	1-6.7	113.75	146.50	.097	.232	.444	.773	8.66	2540	3700
		1-5.65	42-58	1-4.5	51.5-67.6	1-4.5	1-6.25	1-6.25	117.81	145.5	.105	.284	.373	.762	9.62	2660	3170 -
		1-4.56	55-45	1-3.8	65.0-49.8	1-4.07	1-5.20	1-5.57	113.00	143.0	.120	.350	.213	.743	10.40	2350	3390
		1-3.56	75-25	1-3.1	84.9-26.4	1-3.6	1-4.1	1-4.8	106.12	140.5	.141	.439	.140	.720	12.55	2560	3790 -
		1-2.71	95-5	1-2.6	97.5-4.6	1-3.56	1-3.15	1-4.25	98.31	138.5	.168	.505	.025	.698	14.30	3000	4120
27	12	1-6.05	33-67	1-5.1	36.5-73.0	1-4.64	1-6.8	1-6.4	111.37	146.5	.099	.229	.444	.772	8.40	2700	3530
		1-5.43	42-58	1-4.5	47.0-67.2	1-4.5	1-6.1	1-6.1	113.43	146.5	.108	.282	.376	.766	9.10	2703	4000
		1-4.45	55-45	1-3.8	60.0-48.5	1-4.25	1-5.1	1-5.7	110.18	145.5	.124	.355	.276	.755	10.20	3030	4100
		1-3.60	75-25	1-3.1	81.0-26.4	1-3.94	1-4.13	1-5.2	109.00	143.5	.144	.452	.144	.740	11.55	3000	4310
		1-2.90	95-5	1-2.6	98.5-5.0	1-3.7	1-3.4	1-4.7	104.68	142.5	.165	.530	.027	.722	13.65	2950	4660
28	13	1-6.24	33-67	1-5.1	38.5-70.8	1-4.8	1-7.0	1-6.7	115.0	146.0	.096	.226	.446	.768	8.16	2260	3210
		1-5.57	42-58	1-4.5	49.3-66.2	1-4.5	1-6.3	1-6.3	116.25	145.0	.104	.280	.375	.759	8.91	2620	3660
		1-4.53	55-45	1-3.8	62.1-49.5	1-4.05	1-5.1	1-5.5	112.00	143.0	.120	.344	.272	.736	10.50	2700	3950
		1-3.58	75-25	1-3.1	82.9-26.7	1-3.57	1-4.1	1-4.7	108.50	140.5	.140	.431	.140	.711	12.60	2610	3420
		1-2.76	95-5	1-2.6	96.0-5.	1-3.5	1-3.25	1-4.2	99.70	139.2	.166	.498	.025	.689	14.60	2730	3800 -

TABLE V PART 1

Class 1 - Sand passing No. 4 - Pebbles retained on No. 4 passing 1½"																		
Series No	Sand No	Proportions: Weight: Cement to Aggregate	Weight: Sand to Pebbles	Loose Volume: Cement to Aggregate	Loose Volume: Sand to Pebbles	Loose Volume: Computed for Equivalent Str.	Absolute Vol.: As Used	Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggregate	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. of Green Concrete: Cement(c)	Absolute Volume Parts of Unit Vol. of Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol. of Green Concrete: Pebbles(p)	Absolute Volume Parts of Unit Vol. of Green Concrete: c+s+p = Density	Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.: Age 28 Days	Crushing Strength Lbs. Per Sq. In.: Age 6 Mos.
29.	5	1-6.46	33-67	1-5.1	372-80	1-4.67	1-7.2	1-6.75	119.06	145.0	.093	.229	.445	.765	7.92	2190	2400
		1-5.25	42-58	1-4.5	500-696	1-4.46	1-6.5	1-6.5	120.00	145.5	.101	.285	.373	.759	9.47	2332	3130
		1-4.70	55-45	1-3.8	637-526	1-4.25	1-5.4	1-6.0	116.43	145.0	.117	.355	.275	.747	11.0	2677	3820
		1-3.74	75-25	1-3.1	838-284	1-3.9	1-4.3	1-5.4	113.43	142.2	.138	.449	.142	.729	12.1	2930	4000
		1-2.89	95-5	1-2.6	980-54	1-3.7	1-3.35	1-4.8	104.37	140.7	.163	.521	.026	.710	14.1	3300	4160
30	15	1-6.25	33-67	1-5.1	380-766	1-4.25	1-6.95	1-6.07	114.25	145.0	.096	.227	.440	.763	8.2	2730	3180
		1-5.57	42-58	1-4.5	482-676	1-4.47	1-6.3	1-6.3	116.12	147.0	.105	.286	.378	.769	8.9	2810	3840
		1-4.64	55-45	1-3.8	621-519	1-4.4	1-5.3	1-6.1	114.68	146.2	.122	.361	.282	.765	9.45	3060	4130
		1-3.95	75-25	1-3.1	887-303	1-4.2	1-4.55	1-5.8	113.07	142.5	.132	.456	.145	.733	10.7	3090	4120
		1-2.85	95-5	1-2.6	970-50	1-3.7	1-3.3	1-4.6	103.12	141.5	.167	.525	.026	.718	12.9	3320	4530
31	16	1-5.89	33-67	1-5.1	351-725	1-4.2	1-6.57	1-5.6	109.87	143.7	.098	.218	.426	.742	8.5	2450	2960
		1-5.36	42-58	1-4.5	451-654	1-4.42	1-6.0	1-6.0	112.00	145.6	.108	.275	.371	.754	9.2	2430	3050
		1-4.49	55-45	1-3.8	584-50.	1-4.3	1-5.04	1-5.8	111.06	147.0	.124	.347	.278	.749	10.6	2660	3420
		1-3.60	75-25	1-3.1	785-274	1-4.0	1-4.07	1-5.3	109.06	145.6	.145	.445	.145	.735	11.6	3190	4100
		1-2.95	95-5	1-2.6	970-54	1-3.7	1-3.35	1-4.8	106.56	143.5	.165	.527	.027	.719	12.5	3410	4160
32	17	1-6.29	33-67	1-5.1	386-778	1-4.55	1-7.1	1-6.4	115.93	145.6	.094	.225	.441	.760	8.9	2380	2830
		1-5.58	42-58	1-4.5	496-670	1-4.46	1-6.3	1-6.3	116.56	146.2	.104	.280	.374	.758	9.7	2500	3210
		1-4.60	55-45	1-3.8	637-513	1-4.2	1-5.2	1-5.8	113.75	145.0	.120	.350	.276	.746	10.35	2925	3430
		1-3.68	75-25	1-3.1	830-277	1-3.8	1-4.2	1-5.2	111.87	143.0	.140	.445	.143	.728	11.75	3110	3970
		1-2.92	95-5	1-2.6	980-50	1-3.65	1-3.23	1-4.5	101.87	141.0	.166	.510	.026	.702	13.9	3350	4280

TABLE V PART 2

Class 3 - Sand passing No. 8 - Pebbles retained on No. 8 and passing 1½"																	
Series No	Sand No	Proportions: Weight: Cement to Aggregate	Weight: Sand to Pebbles	Loose Volume: Cement to Aggregate	Loose Volume: Sand to Pebbles	Loose Volume: Computed for Equivalent Str.	Absolute Vol.: As Used	Absolute Vol.: Computed for Equivalent Str	Weight Per Cu Ft: Aggregate	Weight Per Cu Ft: Green Concrete	Absolute Volume Parts of Unit Vol of Green Concrete: Cement (c)	Absolute Volume Parts of Unit Vol of Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol of Green Concrete: Pebbles (p)	Absolute Volume Parts of Unit Vol of Green Concrete: c+s+p = Density	Per Cent Water in Mix - Weight	Crushing Strength Lbs. Per Sq. In.: Age 28 Days	Crushing Strength Lbs. Per Sq. In.: Age 6 Mos
33	1	1-10.93	33-67	1-8.5	397-750	1-7.67	1-11.7	1-10.9	114.25	143.3	.060	.238	.465	.763	8.53	1230	1735
		1-8.62	42-58	1-7.0	512-657	1-7.0	1-9.9	1-9.8	115.65	144.4	.069	.291	.384	.744	10.20	1180	1935
		1-6.76	55-45	1-5.6	657-497	1-6.4	1-7.62	1-8.8	113.5	139.7	.084	.359	.281	.724	11.40	1450	2070
		1-4.87	75-25	1-4.35	840-248	1-6.3	1-5.64	1-8.1	106.25	138.4	.107	.458	.146	.711	12.60	1670	2640
		1-3.64	95-5	1-3.5	980-45	1-5.85	1-4.16	1-6.95	97.81	135.2	.132	.524	.026	.682	14.30	1590	2530
34	11	1-10.3	33-67	1-8.5	392-746	1-7.3	1-11.5	1-10.1	113.75	139.5	.059	.232	.449	.740	8.58	713	1023
		1-8.70	42-58	1-7.0	516-669	1-7.0	1-10.0	1-10.0	117.82	139.6	.067	.269	.381	.737	9.22	1,012	1395
		1-6.73	55-45	1-5.6	646-497	1-6.8	1-7.73	1-9.35	113.0	139.5	.083	.362	.280	.725	11.00	1250	2140
		1-5.0	75-25	1-4.35	843-264	1-6.4	1-5.79	1-8.4	108.12	135.2	.104	.457	.145	.706	12.40	1595	2660
		1-3.66	95-5	1-3.5	972-45	1-6.37	1-4.27	1-7.6	98.31	133.0	.130	.529	.027	.686	14.50	2100	3050
35	12	1-10.12	33-67	1-8.5	366-733	1-7.3	1-11.4	1-10.1	111.37	143.2	.061	.233	.462	.756	7.84	1023	1440
		1-8.45	42-58	1-7.0	473-643	1-7.0	1-9.5	1-9.5	113.43	143.0	.071	.286	.387	.744	9.55	1170	1690
		1-6.56	55-45	1-5.6	60-484	1-6.65	1-7.33	1-8.9	110.18	141.7	.088	.358	.287	.733	10.30	1615	2340
		1-5.04	75-25	1-4.35	812-267	1-6.1	1-5.7	1-8.1	109.0	140.0	.107	.459	.151	.717	11.40	1935	3020
		1-3.90	95-5	1-3.5	936-48	1-5.04	1-4.41	1-6.9	104.68	136.5	.128	.537	.028	.693	13.80	1887	2980
36	13	1-10.4	33-67	1-8.5	382-753	1-7.6	1-11.75	1-10.6	115.0	141.2	.058	.230	.453	.742	8.50	778	1395
		1-8.65	42-58	1-7.0	491-659	1-7.0	1-9.06	1-9.9	116.25	140.2	.067	.268	.379	.720	10.15	950	1290
		1-6.68	55-45	1-5.6	623-493	1-6.9	1-7.58	1-9.4	112.0	139.5	.084	.355	.282	.721	11.10	1213	2300
		1-5.03	75-25	1-4.35	823-264	1-6.26	1-5.67	1-8.25	108.5	136.5	.104	.446	.144	.694	12.35	1670	2600
		1-3.70	95-5	1-3.5	952-45	1-6.3	1-4.23	1-7.6	99.7	135.5	.130	.523	.027	.680	14.35	1740	2570

TABLE V PART 3

Class 3 - Sand passing No 4 - Pebbles retained on No 4 and passing 1½"

Series No.	Sand No.	Proportions: Weight: Cement to Aggregate	Proportions: Weight: Sand to Pebbles	Proportions: Loose Volume: Cement to Aggregate	Proportions: Loose Volume: Sand to Pebbles	Proportions: Loose Volume: Computed for Equivalent Str.	Proportions: Absolute Vol.: As Used	Proportions: Absolute Vol.: Computed for Equivalent Str.	Weight Per Cu. Ft.: Aggregate	Weight Per Cu. Ft.: Green Concrete	Absolute Volume Parts of Unit Vol. of Green Concrete: Cement (c)	Absolute Volume Parts of Unit Vol. of Green Concrete: Sand (s)	Absolute Volume Parts of Unit Vol. of Green Concrete: Pebbles (p)	Absolute Volume Parts of Unit Vol. of Green Concrete: c+s+p = Density (d)	Per Cent Water in Mix: Weight	Crushing Strength Lbs. Per Sq In.: Age 28 Days	Crushing Strength Lbs. Per Sq In.: Age 6 Mos.
37	5	1:10.70	33:67	1:8.5	392:800	1:6.36	1:12.2	1:9.20	11906	1432	.050	.242	.466	.766	7.22	1190	1550
		1:8.95	42.58	1:7.0	500:696	1:7.0	1:10.15	1:10.15	12000	1465	.070	.307	.404	.781	8.05	1625	2480
		1:6.95	55:45	1:5.6	635:524	1:6.66	1:7.86	1:9.4	11643	1455	.087	.385	.298	.770	8.95	1560	2860
		1:5.25	75:25	1:4.35	845:284	1:5.4	1:6.1	1:7.4	11343	1400	.103	.476	.150	.729	11.3	1060	2880
		1:3.80	95:5	1:3.5	985:52	1:5.6	1:4.5	1:7.1	10437	1390	.131	.562	.028	.721	11.8	1926	3000
38	15	1:10.3	33:67	1:8.5	382:767	1:6.63	1:11.6	1:9.2	11425	1430	.061	.241	.465	.767	6.83	1325	1930
		1:8.65	42:58	1:7.0	495:674	1:7.0	1:9.8	1:9.8	11612	1450	.072	.304	.400	.776	7.69	1400	2035
		1:6.83	55:45	1:5.6	640:516	1:6.6	1:7.0	1:9.2	11468	1453	.087	.363	.297	.767	9.06	2160	3000
		1:5.27	75:25	1:4.35	866:285	1:6.1	1:6.1	1:8.4	11387	1430	.106	.490	.155	.751	10.2	2250	3200
		1:3.84	95:5	1:3.5	995:516	1:6.6	1:4.5	1:6.0	10312	1395	.130	.555	.028	.713	12.8	2590	3740
39	16	1:9.75	33:67	1:8.5	326:736	1:6.53	1:11.0	1:8.7	10907	1407	.062	.229	.454	.745	7.7	1310	1470
		1:8.35	42:58	1:7.0	451:650	1:6.9	1:9.4	1:9.4	1120	1443	.073	.292	.393	.758	8.15	1800	2870
		1:6.62	55:45	1:5.6	583:498	1:6.8	1:7.4	1:9.2	11106	1450	.090	.370	.295	.755	9.3	1925	2670
		1:5.15	75:25	1:4.35	788:274	1:6.4	1:5.7	1:8.5	10906	1435	.111	.477	.155	.743	10.1	2510	3380
		1:3.96	95:5	1:3.5	970:533	1:5.08	1:4.5	1:7.6	10656	1425	.133	.570	.029	.722	10.7	2840	3740
40	17	1:10.5	33:67	1:8.5	389:777	1:6.64	1:11.7	1:9.6	11593	1410	.059	.233	.457	.749	7.6	1260	1640
		1:8.7	42:58	1:7.0	497:677	1:6.9	1:9.8	1:9.6	11656	1428	.070	.293	.390	.753	8.45	1490	1960
		1:6.70	55:45	1:5.6	636:512	1:6.75	1:7.75	1:9.3	11975	1430	.006	.386	.290	.744	10.0	1665	2420
		1:5.18	75:25	1:4.35	85.2:280	1:6.1	1:5.9	1:8.3	11187	1400	.105	.468	.150	.723	11.2	2150	2980
		1:3.8	95:5	1:3.5	982:51	1:5.8	1:4.33	1:7.2	10187	1375	.131	.540	.027	.698	12.9	2400	3230

TABLE V PART 4

IV. THEORY FOR MAKING CONCRETES OF EQUIVALENT STRENGTH, USING GRAVELS OF VARYING SAND CONTENT — THE "SAND" METHOD

The Theory. The theory of the "sand" method is based upon the assumption that there is a direct relation between the strength of concrete and the ratio.

$$\frac{c}{1-(c+s+p)} = \frac{c}{1-d}$$

in which c = absolute volume of cement, s = absolute volume of sand particles, and p = absolute volume of pebbles in a unit volume of freshly made concrete; d = coefficient of density = absolute volume of solid material in a unit volume of freshly made concrete = c + s + p; and 1 — d = volume of air and water voids. By absolute volume of a granular material is meant the actual sum of the volumes of all of the particles; it is expressed as the fractional part of the total space occupied by the material.

This principle was presented with reference to sand mortars in 1897 by R. Feret. Figure 9 is plotted from researches published by Mr. Feret in Bulletin de la Societe d' Encouragement pour l' Industril Nationale 1897, Vol. II.

Figures 10-11-12 corroborating the correctness of the principle are plot-

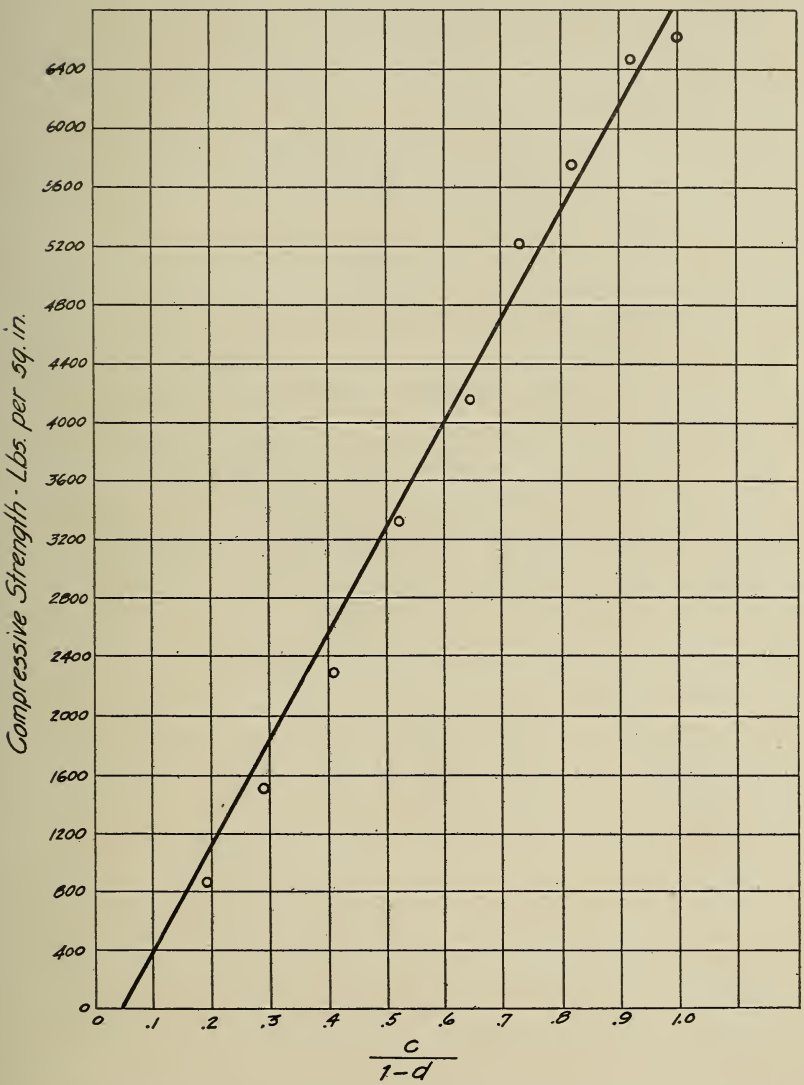


FIG. 9 — RELATION OF CRUSHING STRENGTH TO THE CEMENT-VOIDS RATIO OF THE CONCRETE. From data published in 1879 by R. Fert.

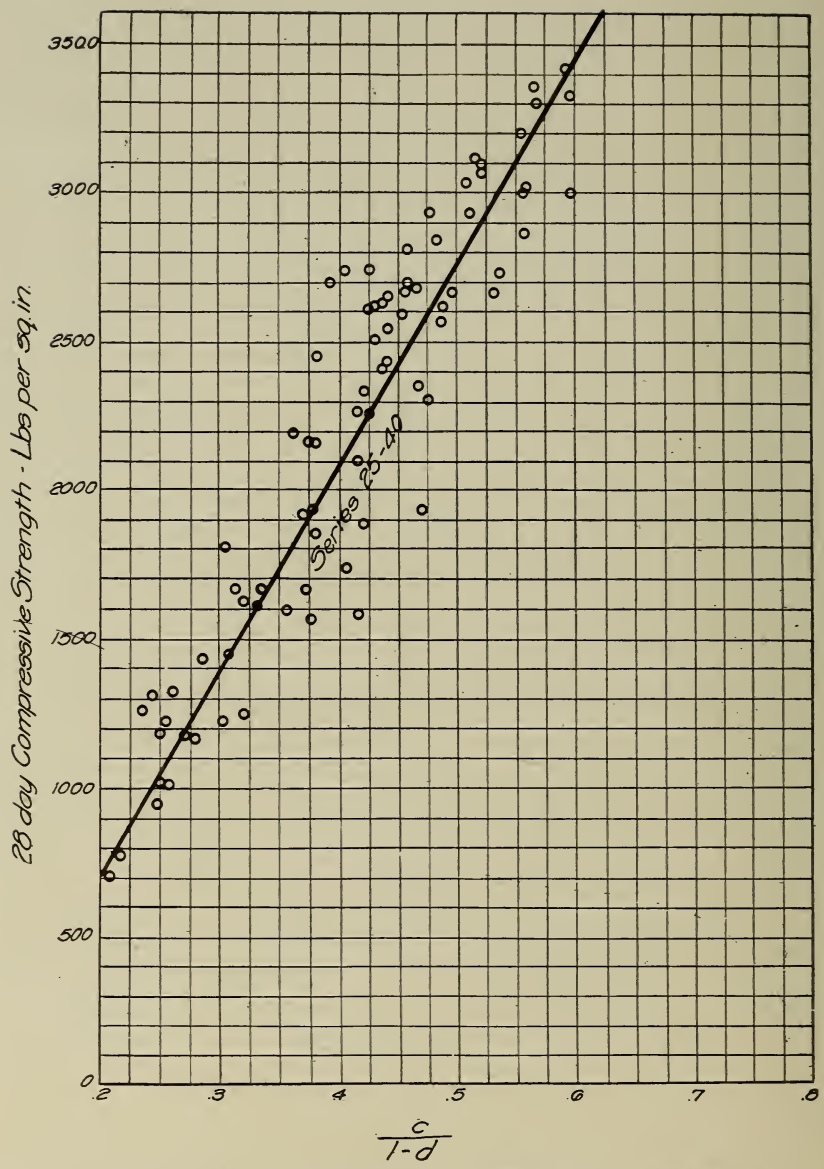


FIG. 10 — RELATION OF CRUSHING STRENGTH TO CEMENT-VOIDS RATIO, SERIES 25-40.

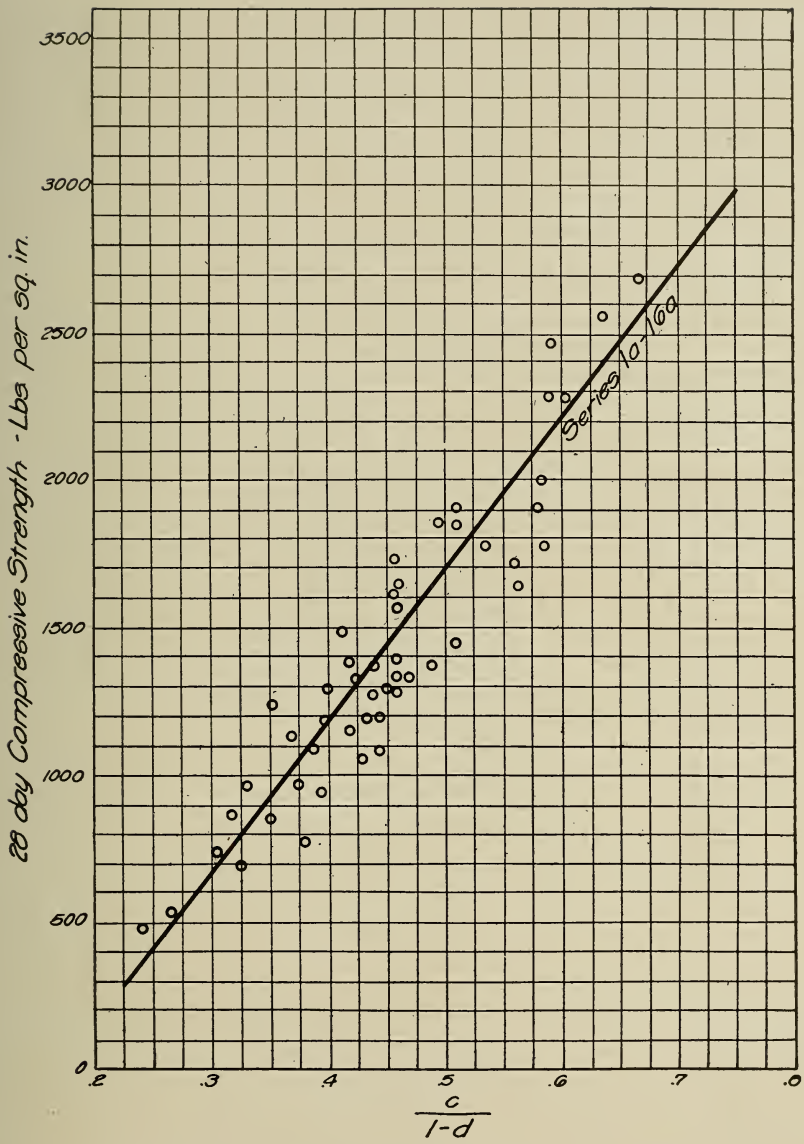


FIG. 11 — RELATION OF CRUSHING STRENGTH TO CEMENT-VOIDS RATIO, SERIES 1A TO 16A.

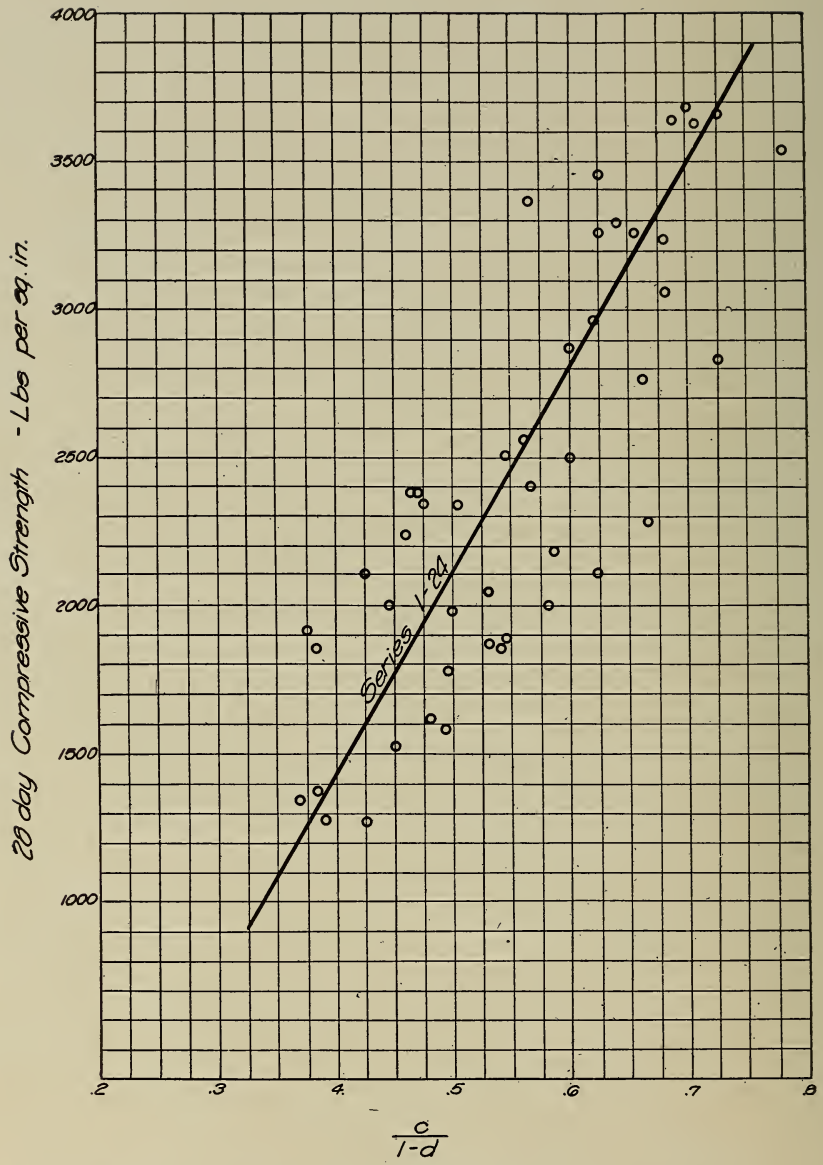


FIG. 12 — RELATION OF CRUSHING STRENGTH TO CEMENT-VOIDS RATIO, SERIES 1-24.

ted from the data accumulated in the tests reported in Tables III and IV.* The tests grouped on each diagram are comparable by reason of being made from the same cement, similar materials and subjected to the same conditions as to making, molding and curing. Each point is derived from the average of tests from 5 specimens. This relation is further verified by tests by the U. S. Bureau of Standards, reported by Wig, Williams and Gates in Technologic Paper No. 58. A diagram similar to figures 9-10-11-12 plotted from this data is published in Johnson's "Materials" rewritten by Professor M. O. Withey.

Application. Assuming that $\frac{c}{1-d}$ should be equal for concretes of equivalent strength, new proportions were computed for each of the series of tests shown in Tables III, IV and V. In each series the new proportions were computed so as to be equivalent to the one containing 42 percent of sand. That is, the proportions were adjusted for each percentage of sand to make the computed value of $\frac{c}{1-d}$ equal to the actual value of $\frac{c}{1-d}$ of the mixture containing 42 percent of sand. The method of computation is illustrated as follows:

DATA CONCERNING PROPORTIONS FROM TYPICAL SERIES (NO. 30)

Percent of Sand in Aggregate, by Weight	c	s	p	d	$\frac{c}{1-d}$
33	0.096	0.227	0.440	0.763	.....
42	0.105	0.286	0.378	0.769	0.455
55	0.122	0.361	0.282	0.765	.....
75	0.132	0.456	0.145	0.733	.....
95	0.167	0.525	0.026	0.718	.....

In order to arrange the proportions for equivalent strength it is necessary to so change the relation between the absolute volumes of cement and the aggregate that the ratio $\frac{c}{1-d}$ will in each case become equal to 0.455. The adjustment can be made by increasing or decreasing c and decreasing or increasing s + p, so that d will be unchanged.

Let c′, s′ and p′ be the new values required for c, s, and p, respectively. As explained before, these values are the percentages of absolute volumes of materials in a unit volume of freshly made concrete.

$$\frac{c'}{1-d} = \frac{c'}{1-(c'+s'+p')} = 0.455$$

* This principle is further corroborated by Prof. A. N. Talbot. Proceedings Am. Soc. for Testing Materials 1921.

Therefore, to convert the mixture containing 33 percent of sand:

$$d = .763, \text{ therefore}$$

$$\frac{c'}{1 - 0.763} = 0.455$$

$$c' = 0.108$$

$$d = c' + s' + p'$$

$$0.763 = 0.108 + (s' + p')$$

$$(s' + p') = 0.655$$

Accordingly the ratio of absolute volume of cement to absolute volume of total aggregate, required to make a proportion using the 33 percent sand mixture equivalent to the 42 percent sand mixture is:

$$108 : 655, \text{ or } 1 : 6.7$$

New proportions on a basis of absolute volumes for the 55, 75, and 95 percent mixtures were computed in the same way.

This theory is approximate, not rigorous, for when the concrete is actually made, the density d will be affected a small amount. The result obtained, however, is within the probable range of accuracy in the making of the concrete.

TABLE VI. COMPUTED PROPORTIONS

Computed Proportions Required to Produce Concrete Equivalent in Strength to the Mixture in Each Series Containing 42 Percent of Sand

(a) Division Between Sand and Pebbles ¼"

Series No.	Based Upon $\frac{c}{1-d}$ =	Proportions by Weight for Percent of Sand				
		33	42	55	75	95
5	.555	.....	1:4.7	1:4.8	1:3.7	1:3.3
6	.555	.....	1:4.7	1:4.8	1:3.1	1:2.9
7	.504	.....	1:4.7	1:4.8	1:3.5	1:3.2
13	.428	.....	1:7.1	1:6.2	1:5.8	1:4.8
14	.374	.....	1:7.2	1:6.1	1:5.2	1:4.2
15	.392	.....	1:7.2	1:6.2	1:5.8	1:4.7
13a	.264	.....	1:8.3	1:7.7	1:6.8	1:6.0
15a	.332	.....	1:8.3	1:6.8	1:5.7	1:4.2
16a	.378	.....	1:8.4	1:6.0	1:5.6	1:4.1
5a	.440	.....	1:5.3	1:4.7	1:3.8	1:3.2
7a	.452	.....	1:5.4	1:4.6	1:3.6	1:3.1
8a	.448	.....	1:5.4	1:4.4	1:3.8	1:2.9
29	.420	1:5.7	1:5.5	1:5.1	1:4.6	1:4.1
30	.455	1:5.2	1:5.4	1:5.2	1:4.9	1:3.9
31	.439	1:4.8	1:5.1	1:4.9	1:4.5	1:4.1
32	.430	1:5.5	1:5.4	1:4.9	1:4.4	1:3.8
37	.319	1:7.8	1:8.7	1:8.0	1:6.3	1:6.0
38	.321	1:7.8	1:8.3	1:7.8	1:7.2	1:5.8
39	.301	1:7.4	1:8.0	1:7.8	1:7.2	1:6.5
40	.283	1:8.2	1:8.3	1:7.9	1:7.1	1:6.1

TABLE VI (Continued)

(b) Division Between Sand and Pebbles ⅛″

Series No.	Based Upon $\frac{c}{1-d}$ =	Proportions by Weight for Percent of Sand				
		33	42	55	75	95
2	.575	.....	1:4.8	1:4.1	1:3.1	1:2.6
10	.367	.....	1:7.1	1:6.8	1:5.2	1:4.5
1a	.453	.....	1:5.3	1:4.9	1:4.3	1:3.5
3a	.451	.....	1:5.3	1:4.8	1:3.8	1:3.1
4a	.385	.....	1:5.4	1:5.3	1:4.6	1:3.8
9a	.320	.....	1:8.3	1:7.3	1:6.3	1:5.2
11a	.305	.....	1:8.2	1:7.7	1:6.4	1:5.0
12a	.261	.....	1:9.4	1:8.2	1:7.2	1:5.5
25	.441	1:5.7	1:5.3	1:4.8	1:4.0	1:3.6
26	.441	1:5.7	1:5.3	1:4.7	1:4.1	1:3.6
27	.462	1:5.5	1:5.2	1:4.9	1:4.4	1:4.0
28	.432	1:5.7	1:5.4	1:4.7	1:4.0	1:3.6
33	.269	1:9.3	1:8.3	1:7.5	1:6.9	1:5.9
34	.255	1:8.6	1:8.5	1:8.0	1:7.2	1:6.5
35	.277	1:8.6	1:8.1	1:7.6	1:6.9	1:5.9
36	.246	1:9.0	1:8.4	1:8.0	1:7.0	1:6.5

(c) Sand ⅛″ Down; Pebbles ¼″ Up

Series No.	Based Upon $\frac{c}{1-d}$ =	Proportions by Weight for Percent of Sand				
		33	42	55	75	95
21	.377	.....	1:7.2	1:6.3	1:6.0	1:5.2
22	.387	.....	1:7.1	1:6.3	1:5.4	1:4.3
17	.540	.....	1:4.6	1:4.3	1:3.6	1:3.2
18	.558	.....	1:4.7	1:4.3	1:3.2	1:2.9

The proportions thus derived are by absolute volumes. To make these proportions usable it is necessary to convert them to a weight basis. Assuming specific gravity of cement = 3.15, and that of the aggregate = 2.68, absolute volume proportion of aggregate (cement = 1) may be changed to weight proportion by the following equation:

$$\text{Aggregate (weight)} = \text{aggregate (absolute)} \times \frac{2.68}{3.15}$$
$$= \text{aggregate (absolute)} \times .85$$

Table VI shows the proportions by weight as computed for equivalent strength. Figure 13 shows graphically the relation between proportion for equivalent strength and percentage of sand in the gravel, for each series independently.

The conclusion drawn from a study of these diagrams is this: The relation between proportions by absolute volumes to give equivalent strength, and sand content of the aggregate, varies uniformly and at approximately the same rate for all degrees of quality of concrete. The line AB in the diagram 13 is established to indicate this rate of variation as an average.

To make use of this diagram to determine the proportions to use with a given aggregate having a certain sand content, it is necessary first to assume an aggregate and proportion known to be satisfactory. Locate

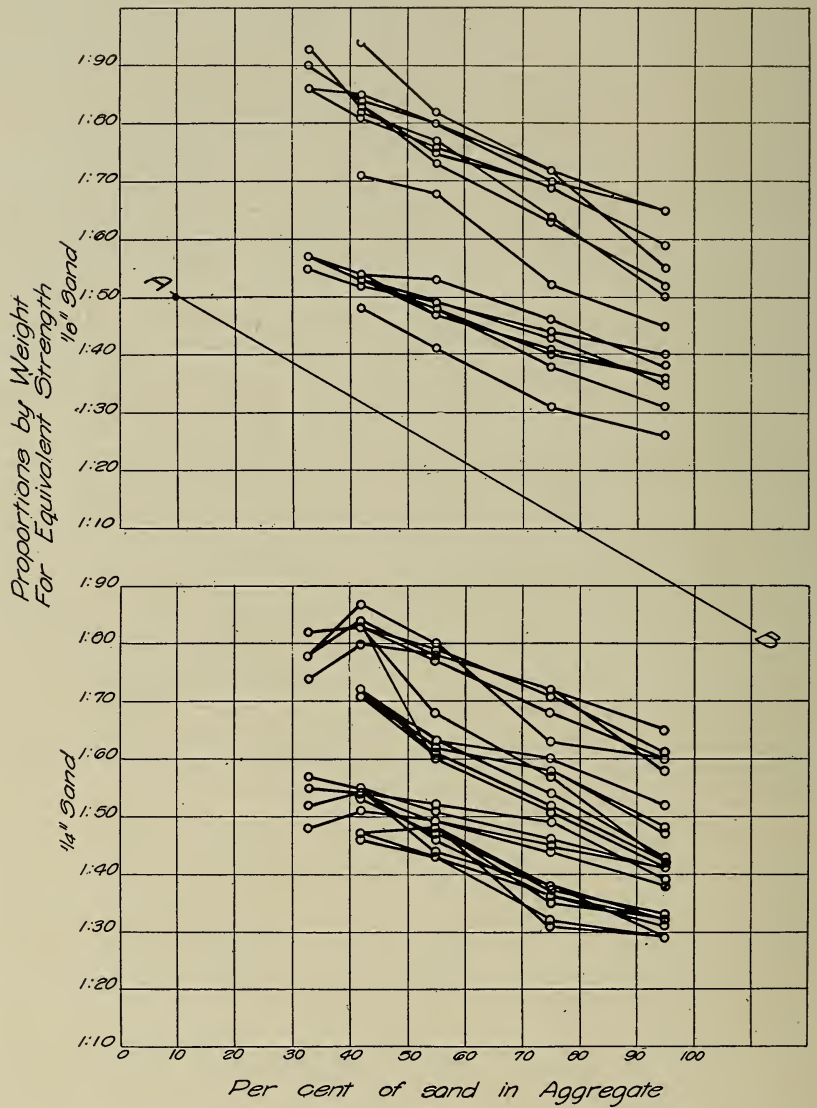


FIG. 13 — THIS DIAGRAM SHOWS THE RATE OF DECREASE IN THE RATIO OF CEMENT TO TOTAL AGGREGATE NECESSARY TO PRODUCE CONCRETE OF EQUIVALENT STRENGTHS IN EACH SERIES OF TESTS AS THE SAND CONTENT OF THE GRAVEL INCREASES. Plotted from data in table 6.

the point representing this known condition and draw a line through it parallel to AB. Then pick from this line of proportions the proportion corresponding to the given aggregate.

To make a single line diagram of general application, the line AB (Fig.13) is plotted on figure 14 using for ordinates the decrease in parts of aggregate, and for abscissas the increase in percentage of sand in the aggregate. This diagram can be used for determining proportions in case the proper data are at hand, or for writing a table of proportions for equivelent mixtures of cement and pit-run gravels in general. Such a table could not be exact for all materials, but it would give very reasonable proportions to use with Iowa gravels.

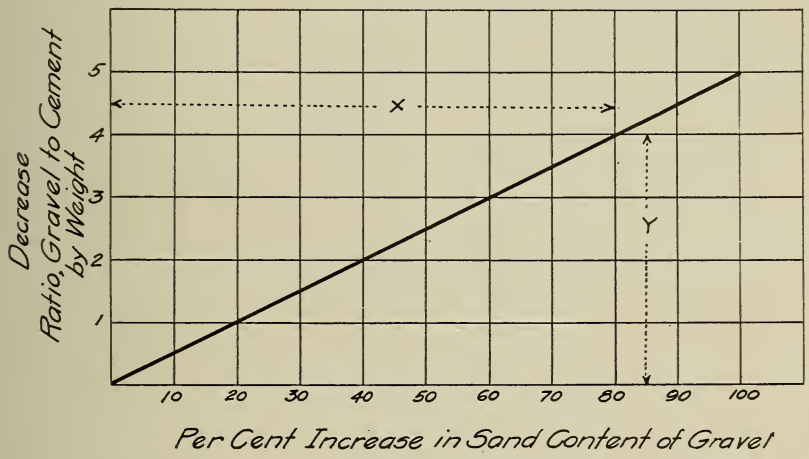


FIG. 14 — THEORETICAL DIAGRAM FOR DESIGNING CONCRETE MIXTURES CONTAINING VARIOUS PERCENTAGES OF SAND IN THE GRAVEL, EQUIVALENT TO ANY PREDETERMINED BASE MIXTURE.

Use of Method. To determine the amount of cement to use with a given pit-run gravel to yield a concrete equivalent to a given mixture of sand and gravel:

1. Reduce the proportion of the standard mix to the basis of weight.
2. Determine from figure 14 decrease in parts of aggregate corresponding to increase in percentage of sand in aggregate and change the proportions accordingly.

Formula for computing item 2. (See Figure 14)

$$\tan a = \frac{4.0}{80} = .05$$

$$y = x \tan a = 0.05\, x$$

Example. Assume that an aggregate containing 42 percent sand, and weighing 112 lb. per cu. ft., makes a satisfactory concrete in the

proportion 1:4½ loose volume. What proportion should be used with a similar gravel containing 75 percent of sand and weighing 107.1 lb. per cu. ft.?

Change the proportion 1:4½ to a proportion by weight thus:

Assume 94 lbs. cement = 1 cu. ft.
1 cu. ft cement to 4.5 cu. ft aggregate
= 94 lbs. cement to 4.5×112 lbs. gravel,
= 1 lb. cement to $\frac{4.5 \times 112}{94}$
∴ proportion by weight = 1 to 5.36

The increase in the percentage of sand is 33. From the diagram, the corresponding decrease in parts of aggregate is 1.6. Therefore the proportion to use for the gravel containing 75 percent of sand should be 1 to (5.36 — 1.6) = 1 to 3.76.

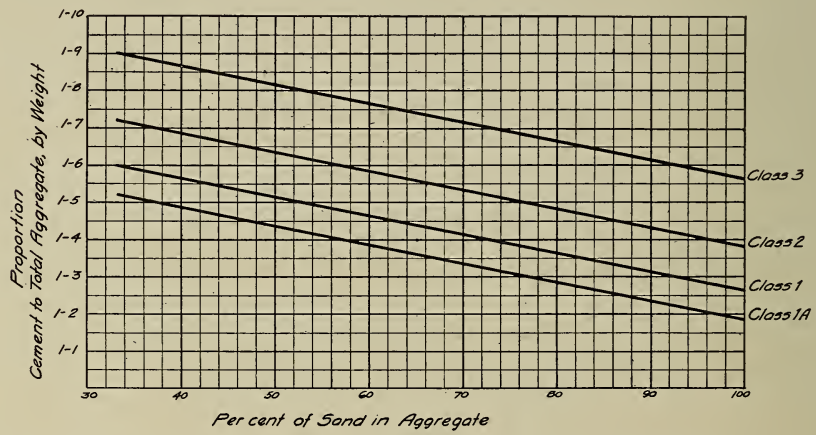


FIG. 15 — PRACTICAL DIAGRAM FOR PROPORTIONING MIXTURES CONTAINING VARIOUS RATIOS OF SAND TO COARSE AGGREGATE, ARRANGED FOR FOUR COMMON CLASSES OF CONCRETE. Proportions by weight.

If it is desired to measure the materials by volume instead of by weight change the above weight relation to a loose volume proporttion as follows:

Wt. per cubic foot of cement = 94 lbs.
Wt. per cubic foot of gravel = 107.1 lbs.
1 lb. cement to 3.76 lb. gravel
= 94 lb. cement to 354 lbs. gravel
= $\frac{94}{94}$ cu. ft. cement to $\frac{354}{107}$ cu. ft. gravel
= 1 to 3.30 by loose volume

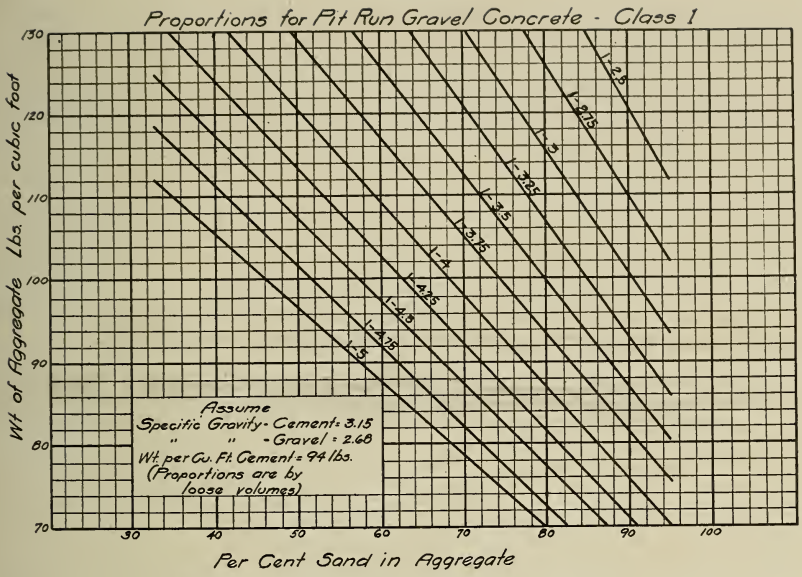


FIG. 16 — VOLUMETRIC PROPORTIONS FOR MIXTURES OF VARYING SAND CONTENT CLASS ONE CONCRETE.

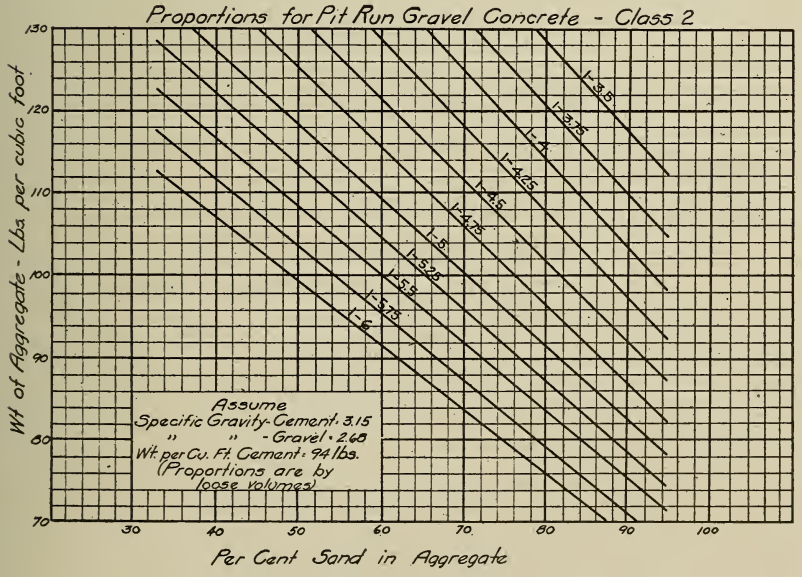


FIG. 17 — SAME AS 16, CLASS TWO CONCRETE.

A general formula for changing from weight to volumetric proportions is as follows:

Let a = parts of gravel to 1 part of cement by weight
b = weight of gravel in lbs. per cubic foot measured loose
94 lbs. = weight of one cubic foot of cement
x = parts of gravel to 1 part cement by volume

$$x = \frac{94a}{b}$$

Diagrams. The diagrams in figure 15 have been arranged for convenience in proportioning gravel concrete both screened and pit-run. The diagrams show proportions by weight, but they can be easily converted into volumetric relations as has just been shown.

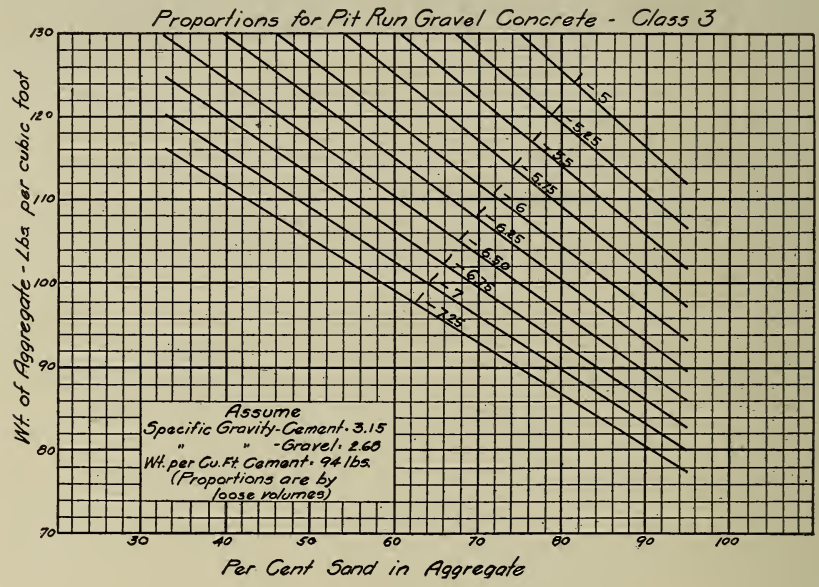


FIG. 18 — SAME AS 16, CLASS THREE CONCRETE.

Class 1-A gives the proportions used by the Iowa Highway Commission for single course concrete pavement, strength 3000 to 4000 lbs. per sq. in.

Class 1, is suitable for reinforced concrete in general, watertight concrete, and base course of 1st class pavements, strength 2400 to 3000 lbs. per sq. in.

Class 2, is suitable for first class foundations, gravity section piers and abutments for bridges, strength 1800 to 2400 lbs. per sq. in.

Class 3, is suitable for large foundations and heavy mass work in general. It should range in strength from 1200 to 1800 lbs. per sq. in.

The diagrams in figures 16, 17 and 18 are arranged for field use in quickly arranging proportions for pit-run gravel on a volume basis. They are derived directly from figure 15.

In applying this theory for proportioning pit-run gravel it should be noted that the method applies only to mixtures ranging from 33 to 100 percent sand in the gravel.

V. VERIFICATION OF THEORY

The system of proportioning, based upon the sand content of the aggregate as developed in Chapter IV has been used in practice and

TABLE VII. PIT-RUN GRAVEL CONCRETE PROPORTIONED BY THE SAND METHOD

Concrete Class	Series No.	Material	Characteristics Mixed Aggregate				Proportions			$\frac{c}{1-d}$	Percentage of Water in Mix, by Weight	Compressive Str'gth at 28 Days, lb. per sq. in.
			Percentage of Sand	Weight lb. per cu. ft.	Fineness Modulus	Surface Area, sq. ft. per 100 lb.	By Weight	By Absolute Volume	By Loose Volume			
I	48	Sand, No. 20; Pebbles No. 22,	33	113.9	533	819	1:6.06	1:6.6	1:5	0.374	10.0	1479
			42	114.7	501	978	1:5.49	1:5.92	1:4.5	0.414	10.0	1945
			55	117.5	458	1220	1:4.97	1:5.87	1:4.0	0.403	10.6	2425
			65	115.7	424	1398	1:4.61	1:5.0	1:3.75	0.426	10.3	2465
			75	113.6	392	1575	1:4.23	1:4.60	1:3.5	0.428	10.9	2565
			85	109.3	360	1753	1:3.78	1:4.10	1:3.25	0.433	11.3	2580
			95	106.9	327	1931	1:3.41	1:3.7	1:3	0.434	12.3	2160
II	49	Pebbles, No. 23.	33	113.9	533	819	1:7.27	1:7.90	1:6	0.308	10.1	1343
			42	114.7	501	978	1:6.71	1:7.28	1:5.5	0.340	9.6	1920
			55	117.5	458	1220	1:6.25	1:6.79	1:5.0	0.343	10.2	1800
			65	115.7	424	1398	1:5.54	1:6.01	1:4.5	0.363	10.3	1955
			75	113.6	392	1575	1:5.14	1:5.58	1:4.25	0.367	10.6	2135
			85	109.3	360	1753	1:4.65	1:5.06	1:4	0.356	11.7	2005
			95	106.9	327	1931	1:4.26	1:4.63	1:3.75	0.373	12.4	1860
III	50	Sand, No. 21;	33	113.9	533	818	1:8.78	1:9.52	1:7.25	0.269	9.4	1113
			42	114.7	501	978	1:8.54	1:9.26	1:7.0	0.284	9.5	1318
			55	117.5	458	1220	1:8.13	1:8.82	1:6.5	0.270	9.9	1415
			65	115.7	424	1398	1:7.38	1:8.14	1:6	0.287	10.1	1416
			75	113.6	392	1575	1:6.95	1:7.54	1:5.75	0.263	11.2	1225
			85	109.3	360	1753	1:6.40	1:6.93	1:5.5	0.263	12.3	1059
			95	106.9	327	1931	1:5.87	1:6.38	1:5.0	0.260	13.7	1031
I	46	Pebbles No. 22,	33	115.6	494	756	1:6.15	1:6.8	1:5	0.447	8.8	3120
			42	115.0	468	915	1:5.50	1:6.3	1:4.50	0.490	8.6	3290
			55	114.4	431	1142	1:4.87	1:5.53	1:4.0	0.536	8.8	3260
			75	112.5	374	1495	1:4.16	1:4.73	1:3.5	0.602	9.3	2970
			96	102.5	320	1839	1:3.27	1:3.8	1:3	0.604	10.8	3090
III	47	Sand, No. 20; Pebbles No. 23.	33	115.6	494	756	1:9.22	1:10.3	1:7.5	0.231	7.7	2000
			42	115.0	468	915	1:8.56	1:9.7	1:7.0	0.293	9.1	1810
			55	114.4	431	1142	1:7.91	1:9.0	1:6.5	0.316	9.25	1950
			75	112.5	374	1495	1:6.88	1:8.0	1:5.75	0.334	10.6	1580
			95	102.5	320	1839	1:5.45	1:6.3	1:5.0	0.371	11.0	1760

found to give concordant results. The reasonableness of the method is well demonstrated in the following independent instances.

(1) Laboratory Tests, Iowa State College. Table VII shows laboratory tests made for the purpose of verifying the method, the tests were made in all respects in a manner similar to those shown in Chapter III. The same consistency was maintained throughout. Series No. 48, 49 and 50 were made about one year after series No. 46 and 47, from different materials, and by a different operator. The consistency was approximately the same in both groups.

(2) Laboratory Tests, United States Bureau of Standards. The following discussion and tables verifying the "sand" method of proportioning pit-run gravel for concrete, are taken from the discussion (by G. M. Williams and Watson Davis, both of the U. S. Bureau of Standards), upon a paper concerning the proportioning of pit-run gravel presented at the 1919 meeting of the American Society for Testing Materials.

Mr. G. M. Williams and Watson Davis (by letter). — With the object of testing the method of proportioning pit-run aggregates proposed by Mr. Crum, the tests presented in this discussion were made.

The tests reported in Table I (VIII, of this bulletin) were designed to duplicate the tests in series No. 48 in Table IV, (VII) of his paper so far as possible with Washington materials. Those reported in Table II (IX) are based on series No. 47 in the same table (VII).

In making the tests reported in Table II (IX) of this discussion, sands of the same gradation as Mr. Crum's sands Nos. 2, 5, and 12 were used in combination with ¾ in. Potomac River gravel. These sands were made by recombining in proper proportions local river sand which had been separated on the proper sieves.

Table IV (XI) gives the properties of the local aggregates used. Compressive strengths reported are the average of tests of three 3 by 6-inch cylinders stored in the damp closet. The weights per cubic foot reported and used are 95 percent of the packed weight obtained by filling a measure in layers one-fourth its height and jolting each layer about ten times. This figure has been found to be practically equal to an average of the weight of poured-in unjolted material and the packed weight.

Concretes within each series were of equal flowabilities as determined on the "flow table." This apparatus which measures flow or "consistency," operates by jolting a measured mass of concrete a given number of times so as to cause the mass to flow or spread concentrically outward. The increase in diameter of the concrete is a measure of the flow. The mixes of Tables I (VIII) and II (IX) had a flow of 180 percent (1.8 times the original diameter), which may be described as a wet road consistency, while the mixes of Table III (X) had a flow of 200 percent, which is a suitable consistency for reinforced concrete work.

In general, the strength results obtained in the tests made indicate that the proposed method of proportioning pit-run materials produces concretes of practically equal strength when the aggregates of these tests are used, and equal flowabilities are obtained.

It should be noted that concretes of Table I (VIII) are comparable and should give equal strengths according to the theory. The same is true of the concrete of Table II (IX). In table III (X), concretes made with the same numbered sand should give equal strengths according to the proposed method. The strength results seem to indicate that, generally the method of proportioning gives strengths that are practically the same. When the sand in the aggregate is less than 50 percent,

there is an indication that the method is not so satisfactory as in the sandier mixes. The method seems to give slightly higher strengths for the sandy mixes, and it is probable that the slope of the curve in figure 3 (13) of Mr. Crum's paper could be decreased (mixes made leaner). The present slope is on the safe side, however.

It should be noted, however, that the proposed method of proportioning as used in practice does not in any way depend upon or use the assumption that strength is a function of $\frac{c}{1-d}$.

TABLE VIII. STRENGTH OF CONCRETES

All Concretes Have the Same Flowability of 180 Percent

Percent of Sand	Weight lb. per cu. ft.	Proportions by Loose Volumes	c	Water Percent by Weight	Compressive Strength lb. per sq. in.	
					7 Days	28 Days
33	118.2	1:5	0.412	8.50	1305	2030
42	121.6	1:4.5	0 412	9.22	1500	2150
55	118.5	1:4.0	0.402	10.32	1685	2510
65	116.9	1:3.75	0.399	10.77	1610	2410
75	114.8	1:3.5	0.399	11.42	1540	2355
85	112.4	1:3.25	0.396	12.12	1600	2435
95	107.4	1:3	0.407	13.11	1710	2780

TABLE IX. STRENGTH OF CONCRETES

All Concretes Have the Same Flowability of 180 Percent

Percent of Sand	Weight lb. per cu. ft.	Proportions by Loose Volumes	c	Water Percent by Weight	Compressive Strength lb. per sq. in.	
					7 Days	28 Days
33	118.2	1:7.5	0.295	8.17	675	1245
42	121.6	1:7	0 261	9.17	630	1380
55	118.5	1:6.5	0.277	9.94	710	1470
75	114.8	1:5.75	0.236	11.95	590	1310
95	107.4	1:5	0.245	14.01	610	1320

TABLE X. STRENGTH OF CONCRETES

All Concretes Have the Same Flowability of 200 Percent

Crum's Sand No.	Percent of Sand	Weight lb. per ft.	Proportions by		c	Water Percent by Weight	Compressive Strength lb. per sq. in.	
			Absolute Volumes	Loose Volumes			7 Days	28 Days
2	50	122	1:7.63	1:5a	0.319	11.82	940	1700
	75	114	1:6.18	1:4.33	0.300	14.22	870	1580
	95	105	1:5.02	1:3.82	0.288	16.78	1055	1830
5	50	114	1:7.13	1:5a	0.372	10.78	1018	1830
	75	113	1:5.68	1:4.02	0.361	12.39	1285	2330
	95	107	1:4.52	1:3.39	0.376	13.62	1480	2500
12	50	119	1:7.43	1:5a	0.356	10.62	1180	2135
	75	116	1:5.98	1:4.12	0.321	12.86	1240	2100
	95	109	1:4.82	1:3.54	0.335	14.72	1310	2330

a A 1:5 mix was assumed for the 50 percent sand concretes and the proportions for the 75 and 95 percent concretes computed by Fig. 3 of Crum's paper.

TABLE XI. CHARACTERISTICS OF AGGREGATES

Aggregate	Percentage of Voids	Weight lb. per cu. ft.	Sieve No. Opening in 0.75	Sieve Analysis: Percent Passing						
			.....	4	8	14	28	48	100
			0.375	0.185	0.093	0.046	0.023	0.046	0.0058
Potomac River Sand	35.4	106	.....	100.00	97.2	87.0	76.6	57.6	17.2	4.4
Potomac River Gravel ¾ in.	39.6	99	100.0	47.4	3.0	.....	.....	.....	.....	.....

(3) **Pavement Base, Belmond, Iowa.** Table XII shows the results of strength tests upon specimens of pit-run gravel concrete, made during the course of construction of pavement base at Belmond, Iowa in 1919. Specimens were 6″ x 12″ cylinders.

TABLE XII

Percent Sand	Proportions	Slump Inches	Age When Tested Days	Crushing Load lbs. per sq. in.
75	1:3¾	1	30	1620
75	1:3¾	1	30	2425
75	1:3¾	1	30	1660
75	1:3¾	1	30	2160
75	1:3¾	1	30	1880
			Average	1949

That this concrete is substantially equivalent in strength to the standard 1:2:3½ mix it was designed to equal, is demonstrated by the following test results on specimens made from the top course of the same pavement, all other conditions being the same.

TABLE XIII

Proportion	Size of Coarse Agg	Slump Inches	Age When Tested Days	Crushing Load lbs. per sq. in.
1:2:3½	¾″ to ¼″	1	30	2175
1:2:3½	¾″ to ¼″	1	30	1933
1:2:3½	¾″ to ¼″	1	30	1820
1:2:3½	¾″ to ¼″	1	30	1980
1:2:3½	¾″ to ¼″	1	30	1780
			Average	1938

(4) **Single Course Concrete Pavement, Iowa Primary Roads, 1920.** Tables XIV and XV show comparative strength tests of specimens made upon ten concrete paving jobs in different parts of the state. Each two results represent one day's work. The specimens were 6″ x 12″ cylinders made and cured as nearly as possible in the same way as the pavement. As might be expected of specimens made in this way, there is a wide variation in the strength of individual specimens, but the average values show a satisfactory uniformity from county to county.

With respect to strength and uniformity, the data indicate that the method of proportioning used will give equivalent results. One variable by which the range in strength may be explained was the fact that the specimens shown in this table were made during September and October, and some were therefore made under rather adverse weather conditions. The specimens shown in column 1, were made under the least modern method in use. The material was quite variable and contained many oversize rocks. The gravel was strung along the sub-grade and measured in wheelbarrows. The two pit-run gravel jobs (Columns 2 and 3) in which the material was handled from large stock piles and accurately measured were the most uniform of all.

TABLE XIV. STRENGTH TESTS — FIELD SPECIMENS

From Paving Projects under Supervision, Iowa Highway Commission, 1920

Age Approximately 3 months

1	2	3	4	5	6	7	8	9	10
Pit-run Gravel Piled on Sub-grade	Pit-run Sand 70 Percent Stock Pile	Pit-run and Gravel 1-2.4-2.4 Stock Pile	Sand and Gravel 1-2.5-2.1 Stock Pile	Sand and Gravel 1-2.5-1.0 Stock Pile	Sand and Gravel 1-2-3.5 Stock Pile	Sand and Gravel 1-2-3.5 Stock Pile	Sand and Gravel 1-2-3.5 Stock Pile	Sand and Gravel 1-2-3.5 Stock Pile	Sand and Gravel 1-2-3.5 Stock Pile
3110	3640	3460	3540	4630	3710	2940	3890	4265	5120
2975	3715	3570	3460	4310	3500	2960	2960	4520	5230
4245	3355	4340	3990	3600	3540	4030	3530	3430	4240
4810	3780	4230	4310	4030	3880	4130	4310	4000	4870
4380	5080	4630	2970	3890	4040	4170	4060	3375	4130
4060	5120	4030	3780	3920	4240	4910	3310	4970	4060
3040	4210	4060	2530	3280	2820	5050	4060	4700	4030
3460	3990	3350	3780	3250	2120	4940	4140	5020	4100
3250	4100	3710	3210	3350	3950	4240	3990	4170	4700
3390	4770	3850	.....	3600	3850	4160	4140	4060	4940
2830	4030	4170	.....	.....	.....	3500	3670	4130	2860
2760	3610	3820	.....	.....	2080	3000	3950	3600	3045
2360	3890	3570	.....	.....	4730	3920	3920	3640	2410
2580	3990	3670	.....	.....	3890	3670	3990	3570	2650
.....	4240	3530	.....	.....	3810	2900	2930	4240	2820
2370	3780	3460	.....	.....	4240	2930	3280	4520	2680
2470	3710	3420	.....	.....	4090	3250	5160	4340	2580
3040	3640	3950	.....	.....	3920	3000	4340	4270	3070
2400	3710	4520	.....	.....	3290	2930	3320	4140	2190
2720	3640	3170	.....	.....	3920	3350	4030	4170	2470
3000	3140	3640	.....	.....	.....	2580	3140	3530	2930
3070	3210	3780	.....	.....	.....	.....	3350	3140	2720
2150	3530	.....	.....	.....	.....	.....	4840	4030	3280
2330	3350	.....	.....	.....	.....	.....	4660	4210	3140
.....	.....	.....	.....	.....	.....	.....	.....	3420	2750
.....	.....	.....	.....	.....	.....	.....	.....	3420	.....
.....	.....	.....	.....	.....	.....	.....	.....	3740	3180
.....	.....	.....	.....	.....	.....	.....	.....	3320	.....
.....	.....	.....	.....	.....	.....	.....	.....	3920	.....
.....	.....	.....	.....	.....	.....	.....	.....	3850	.....
3070	3890	3810	3510	3786	3660	3600	3870	3990	3460

Columns 3 and 4 show results on mixtures made from screened materials proportioned by the method described in this bulletin. Column 5, shows a mixture a trifle richer than the method would require. The numbers above the columns refer to the same jobs in each table and in the diagrams following.

Figure 19 shows graphically the data in tables XIV and XV, the projects being arranged in the same order.

Figure 20, shows the range in variation in the composition of the ag-

TABLE XV. STRENGTH TESTS — FIELD SPECIMENS

From Paving Projects under Supervision, Iowa Highway Commission

Age approximately 6 months

1		2	3	4a	4b		5	6	7	
Pit-run Gravel Piled on Sub-grade		Pit-run Gravel 70% Sand 1:3½ Stock Pile Road Mix	Pit-run Gravel plus Gravel 1:2.4:2.4 Stock Pile Road Mix	Sand and Gravel 1:2.5:2.1 Stock Pile Road Mix	Sand and Gravel 1:2:3.5 Stock Pile Road Mix		Sand and Gravel 1:2.5:1 Stock Pile Central Mix	Sand and Gravel 1:2:3.5 Stock Pile Road Mix	Sand and Gravel 1:2:3.5 Stock Pile Central Mix	
4980	2820	4760	4170	4380	3180	4210	5260	4200	5360	4420
4660	2580	3670	3920	5190	3390	3990	3610	4200	4310	3850
4030	4210	3620	4940	4160	3460	3350	3320	4100	5300	3530
4240	3530	3210	4450	4280	4560	4520	4020	3750	4100	4340
3890	3210	4060	4880	3390	4380	4170	3750	4340	4310	4480
3780	3000	4030	4760	3390	4520	4620	3780	3890	3990	4520
4450	2720	4060	3670	4730	4450	3180	2930	3810	5440	4520
4090	2720	4410	4030	4270	3250	4340	3810	3600	5120	4490
3210	3570	4410	3640	4520	3030	3810	3570	2960	4810	4190
3640	2720	4810	3890	4130	3350	3460	4030	3320	4170	4030
3950	3810	5300	3430	3670	4490	4060	3710	2890	4700	4060
3430	3390	4410	3460	4490	3710	4770	3500	3320	5300	3890
2970	.....	3960	.....	4130	4760	4130(	4600	4490	5330	3780
3140	.....	4200	.....	4700	4240	3750	4370	4450	4910	2830
4310	.....	4690	.....	4520	5720	3950	5500	3140	4310	2890
3990	.....	4480	.....	3670	4940	4700	5050	3950	4910	4480
3750	.....	5160	.....	4590	5760	3890	4630	3950	5160	4770
2930	.....	5840	.....	4090	4810	3640	4310	4240	4810	3990
3280	.....	.....	.....	3960	3780	2820	3600	4100	4940	4170
3320	.....	.....	.....	3110	3420	.....	4030	.....	4130	4700
3460	.....	.....	.....	3670	3780	.....	3890	.....	4630	3530
2960	.....	.....	.....	3640	4700	.....	3920	.....	4200	3920
4380	.....	.....	.....	3390	3740	.....	2360	.....	5010	4020
4060	.....	.....	.....	3530	3820	.....	3990	.....	4520	4700
3390	.....	.....	.....	3710	4450	.....	3810	.....	4560	4100
3390	.....	.....	.....	3460	4380	.....	.....	.....	4420	4240
3210	.....	.....	.....	4060	3600	.....	.....	.....	3290	3850
3320	.....	.....	.....	3530	3530	.....	.....	.....	3640	4560
3460	.....	.....	.....	4340	3560	.....	.....	.....	3710	5830
3600	.....	.....	.....	4100	3850	.....	.....	.....	4270	5790
2720	.....	.....	.....	4170	3610	.....	.....	.....	4030	3106
3000	.....	.....	.....	.....	4130	.....	.....	.....	3530	3030
....	.....	.....	.....	.....	3500	.....	.....	.....	4910	....
Av. 3530		4393	4103	4031	4027		4041	3826	4350	

gregates as finally placed in the pavement, for the same jobs and conditions as shown in Figure 19. In connection with each set of test specimens the cement was washed from a sample of concrete from the same batch and a sieve analysis was made upon the aggregate. In figure 20, the maximum and minimum percentages passing the No. 4 sieve (opening .185 inches) is shown for each project. The shaded area stops at the percentage passing No. 4 sieve, upon which the proportions for the job were based, thus showing the relation between the maximum, minimum, and the proportioning base.

TABLE XV — Continued

8		9		10	11	12	13	
Sand and Gravel 1:2:3.5, Stock Pile Road Mix		Sand and Gravel 1:2:3.5, Stock Pile Road Mix		Sand and Gravel Hauled from pit, Central Mix	Sand and Gravel Stock Pile Road Mix	Sand and Gravel Piled on Sub-grade Road Mix	Sand and Gravel Piled on Sub-grade, Road Mix	
4810	4560	4480	4420	4590	5690	3890	5690	3750
4590	4310	4480	5300	4590	4840	4030	4450	3950
4030	4200	4590	5090	3850	4810	3210	4240	3350
3990	4450	3780	4760	3600	3640	3570	4660	4910
4380	4030	4450	4840	3430	3950	2830	4380	4210
4630	5303	5360	4130	3430	5260	3320	4910	3850
4430	4410	5010	3960	4770	3180	3500	3210	....
4620	5190	5370	5120	4030	3500	3850	3600	....
4490	5010	3820	4560	4340	3990	3740	4380	....
4090	3920	3950	4270	4100	3420	4730	3110	....
3990	4210	4160	4760	4660	4450	3780	4450	....
4560	4130	4030	4560	4160	3435	2930	4840	....
3990	4270	4690	5060	.....	4520	2015	4520	....
5260	5370	4590	4910	.....	2690	3890	4340	....
5120	5340	4200	4770	.....	3180	3000	3920	....
4420	5720	4810	4130	.....	3290	.....	2899	....
3890	5300	4660	4980	.....	2580	.....	3490	....
4450	3350	5220	4030	.....	2890	.....	3350	....
4840	4560	4840	5190	.....	3350	.....	4420	....
3560	4270	4340	.....	.....	3000	.....	3640	....
4140	4760	3990	.....	.....	3180	.....	3250	....
4060	3390	3530	.....	.....	3560	.....	4060	....
4480	.....	3430	.....	.....	3390	.....	4060	....
4870	.....	3740	.....	.....	3710	.....	4340	....
5500	.....	4730	.....	.....	4030	.....	4700	....
5330	.....	5120	.....	.....	3390	.....	4520	....
5330	.....	4910	.....	.....	3710	.....	4620	....
5190	.....	5680	.....	.....	2400	.....	3810	....
5470	.....	5580	.....	.....	2220	.....	4700	....
5830	.....	4340	.....	.....	3780	.....	4340	....
5230	.....	5010	.....	.....	2860	.....	4130	....
4620	.....	4270	.....	.....	.....	.....	4910	....
5300	.....	4490	.....	.....	.....	.....	4590	....
4310	.....	4210	.....	.....	.....	.....	3990	....
4630	.....	3530	.....	.....	.....	.....	3890	....
4490	.....	4420	.....	.....	.....	.....	3640	....
Av.	4603	4540		4130	3610	3590	4145	

It will be noted that the range in composition of the aggregates actually in the concrete, it not any greater for the pit-run material than for mixtures made from screened aggregates. The evidence from the tests reported herein, confirms the conclusion that pit-run gravel when properly handled will yield concrete of as uniform quality as may be ordinarily expected.

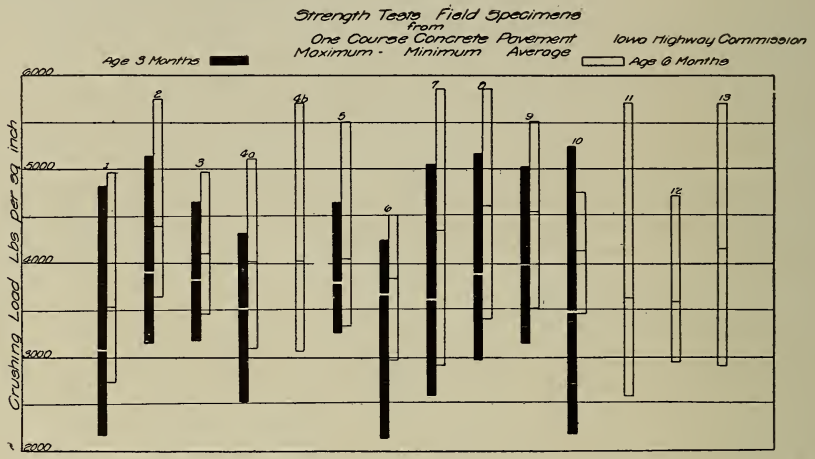


FIG. 19 — DIAGRAM SHOWING THE AVERAGE, MINIMUM AND MAXIMUM CRUSHING STRENGTHS OF SPECIMENS TAKEN IN THE FIELD DAILY ON 13 PROJECTS. Data taken from table numbers XIV and XV. Numbers correspond to numbers in tables XIV and XV.

VI. APPLICATION OF THEORY

Use of Pit-Run Gravel and Mixtures Containing Various Amounts of Sand, It has been demonstrated in preceding chapters that satisfactory concrete can be made from mixtures of aggregates in which the amount of sand ranges from 33 to 100 percent. The only difference between the use of pit-run gravel and screened gravel is the fact that the cement ratio in the case of pit-run must be changed as often as necessary to correct the variations in the material. Outside of the grading, pit-run gravel should be in all respects of as high quality as screened materials. Whether screened or unscreened material should be used is entirely a matter of available material and relative economy.

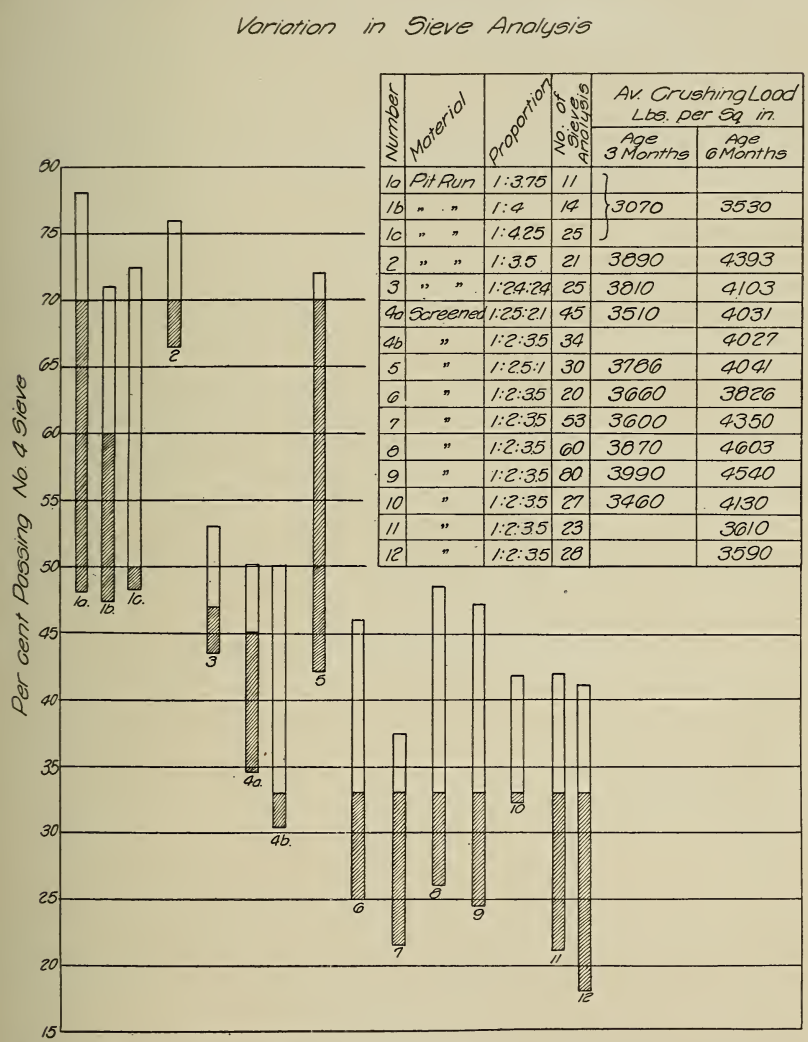
The method of use described in this bulletin is extremely simple of application in the field, and simplicity, in such a case makes for reliability. One test only is required. That is for the percentage of sand in the gravel. If it is not practicable to weigh the gravel when used, a test for weight per cubic foot will also be needed. In this case the procedure is:

1. The percentage of sand is determined as follows:

Apparatus. A small No. 4 sieve, and a scale or balance reading accurately to 1 oz. are required. A regular testing sieve is preferred, but

for rough work a piece of No. 4 commercial wire cloth may be tacked on the under side of a small bottomless box.

Method. A sample containing 10 to 20 lbs. is placed on the No. 4 screen and shaken until the material ceases to pass the sieve. The



Number	Material	Proportion	No. of Sieve Analysis	Av. Crushing Load Lbs. per Sq. in. Age 3 Months	Age 6 Months
1a	Pit Run	1:3.75	11		
1b	" "	1:4	14	3070	3530
1c	" "	1:4.25	25		
2	" "	1:3.5	21	3890	4393
3	" "	1:24:24	25	3810	4103
4a	Screened	1:25:2.1	45	3510	4031
4b	"	1:2:3.5	34		4027
5	"	1:2.5:1	30	3786	4041
6	"	1:2:3.5	20	3660	3826
7	"	1:2:3.5	53	3600	4350
8	"	1:2:3.5	60	3870	4603
9	"	1:2:3.5	80	3990	4540
10	"	1:2:3.5	27	3460	4130
11	"	1:2:3.5	23		3610
12	"	1:2:3.5	28		3590

FIG. 20 — DIAGRAM SHOWING RANGE IN SIEVE ANALYSIS AS DETERMINED ON THE NUMBER FOUR SIEVE, FOR THE JOBS IN TABLES XIV AND XV. Maximum and minimum values as observed are shown. Top of shaded portion indicates percentage passing number four sieve upon which proportions were based. Samples were taken from pavement while fresh and cement removed by washing thru a number 100 sieve.

material which passes the sieve is weighed. This weight is divided by the original weight of the entire sample, and the quotient, multiplied by 100, is the percentage of sand in the pit-run gravel to use in connection with the diagrams in figure 15.

2. From figure 15 the proportion to use for the class of concrete desired is selected.

3. If it is necessary to measure the gravel by volume the above weight relation is converted to volumetric as follows:

Weight per Cubic Foot, — Apparatus. A straight sided measure, of which the capacity can be accurately determined, to hold not less than one-half cubic foot and some method of weighing to the nearest pound are required. A 100 pound spring balance is convenient and easy to carry.

Method. Since materials are measured on the work loose, as shoveled into wheelbarrows or other receptacles, the determination of weight should be made upon material in approximately the same condition. In order to secure comparable results, it is necessary that the procedure be followed exactly.

In placing the material in the measure the shovel is held so that the end rests upon the top of the measure, and the material is allowed to slide off into the measure. When the measure is full, it is struck off level with the straight edge, weighed and the weight of the container subtracted. The remainder is divided by the inside volume of the measure in cubic feet, and the resulting figure is the loose weight per cubic foot of aggregate. The handling of the measure after striking off will cause a shrinkage due to the compacting of the material. No material should be added to fill up the measure. It is the weight of the loose volume that is wanted. Weight per cubic foot does not mean anything, unless the degree of compactness is defined. This is accomplished in this test by specifying the exact method of filling the measure.

Assuming that a cubic foot of cement weighs 94 lbs. then weight proportion $= 1$ to a

$= 94$ to 94 a divide each by the weight per cubic foot then volumetric proportion

$$= \frac{94}{94} \text{ to ax } \frac{94}{\text{wt. per cu. ft. of gravel}}$$

$$= 1 \text{ to ax } \frac{94}{\text{wt. per cu. ft. of gravel.}}$$

When possible to do so it is good practice to get the weight per cubic foot by weighing a volume of the material as actually measured on the job.

Methods of Using Pit-Run Gravel. Pit-run gravel may be used in each of three different cases:

1. Enough cement may be used to make concrete of the desired class from the gravel without change.

2. The gravel may be separated into sand and coarse aggregate by screening, and remixing in pre-determined proportions.

3. The gravel may be made the equivalent of the proportion in case 2 by adding coarse aggregate or sand, as may be required.

Determining Costs. To make a comparative estimate of the costs of the three methods, the following information will be required:

(a) Unit prices of cement, pit-run gravel, screened gravel and crushed stone, and cost of screening.

(b) Quantities of materials required for one cubic yard of concrete.

(c) Percentage of sand in the gravel, by weight, and the relative volumes of sand and gravel a unit volume of the pit-run will yield, and the weight per cubic foot of the pit-run.

Item "a" will depend upon local conditions; "b" may be estimated as shown in the Iowa Highway Commission table of proportions (See Table XVI) and "c" must be determined by test. If a unite volume of pit-run gravel be separated into two sizes it will be found that the sum of the volumes of the two sizes will be more than the original volume. For instance, 1 cu. yd. of pit-run gravel may yield .70 cu. yd. of sand and .50 cu. yd. of coarse aggregate. The percentage of sand to use with the diagram for proportioning pit-run materials under case 1 may be found as follows:

$$\text{Percentage of sand} = \frac{.70}{.70 + .50} = 58.3$$

This figure will agree reasonably close with the percentage determined by separating the sizes by weighing. Therefore, the diagrams will apply

TABLE XVI. IOWA HIGHWAY COMMISSION
TABLE OF PROPORTIONS FOR SCREENED AND UNSCREENED GRAVEL AGGREGATE

Percent sand in aggregate by weight	Proportion by weight		Approximate bbl. cement per cu yd.
	Pit run gravel lb. cement to lb gravel	Screened gravel lb. cement to lb. sand to lb. screened gravel	
33	1:5.18	1:1.71:3.47	1.6
34 to 40	1:4.84	1:1.93:2.91	1.67
41 to 45	1:4.59	1:2.06:2.53	1.74
46 to 50	1:4.34	1:2.17:2.17	1.80
51 to 55	1:4.10	1:2.25:1.85	1.87
56 to 60	1:3.84	1:2.30:1.54	1.95
61 to 65	1:3.60	1:2.34:1.26	2.04
66 to 70	1:3.35	1:2.34:1.01	2.15
71 to 75	1:3.10	1:2.33:0.77	2.26
76 to 80	1:2.86	1:2.29:0.57	2.39
81 to 85	1:2.61	1:2.22:0.39	2.53
86 to 90	1:2.36	1:2.12:0.24	2.71
91 to 95	1:2.12	1:2.01:0.11	2.89
96 to 100	1:1.87	1:1.87	3.13

to either volumetric or weight determinations of the percentage of sand.

Having the above information the procedure is as follows:

(1) The proportion for cement to gravel for case 1 is derived from the diagram Fig. 14.

(2) The proportion of cement to sand to coarse aggregate which would be the equivalent to the mixture of case 1 is assumed. (For Class 1 concrete use 1:2:4; Class 2, use 1:2½:5; Class 3, use 1:3:6.)

(3) The comparative costs are computed:

Example.

Cement	$2.00 per bbl.
Pit-run gravel	1.00 per yd.
Stone	2.00 per yd.
Screening	.50 per yd.

Percentage of sand in gravel, 58.0

Yield of sand	.70 of volume of pit-run
Yield of coarse aggregate	.50 of volume of pit-run

Case 1. Using Pit-Run Straight, Proportion 1:4.0.

Material required for 1 yd. of concrete

Cement	1.68 bbl.
Pit-run	1.00 yd.
1.68 bbl. at $2.00	$3.36
1 yd. pit-run at $1.00	1.00
Material cost	$4.36

Case 2. Screening, and Remixing, Proportions 1:2:4.

Material required:

Cement	1.5 bbl.
Sand	.44 cu. yd.
Pebbles	.88 cu. yd.

Yield of sand and pebbles from pit-run same as before.

To produce .88 yd. of pebbles it will be necessary to buy and screen $\frac{.88}{.50}$ cu. yd. of pit-run = 1.76 cu. yd. The cost of material is therefore:

1.5 bbl. cement, at $2.00	$3.00
1.76 yd. pit-run, at $1.00	1.76
1.76 yd. screening, at $0.50	.88
	$5.64

Case 3, Adding Coarse Material, Proportion 1:2:4.

Material required:

Cement	1.5 bbl.
Sand	.44 cu. yd.
Pebbles	.88 cu. yd.

One yard of this gravel will yield about .70 cu. yd. of sand. Therefore to produce .44 cu. yd. sand $\frac{.44}{.70} = .63$ cu. yd. of pit-run will be required. .63 yd. pit-run will yield .44 yd. sand and .31 yd. stone, leaving .88 — .31 = .57 yd. stone to be added.

Cement 1.55 bbl., at $2.00	$3.00
Pit-run .63 yd., at $1.00	.63
Stone, .57 yd., at $2.00	1.14
	$4.77

The same method of analysis will apply in estimating the relative economy of using different mixtures of sand and coarse aggregate.

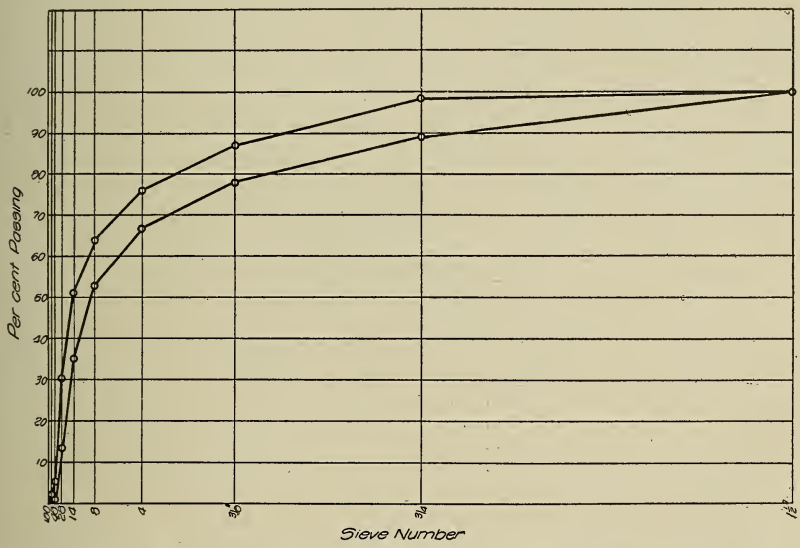


FIG. 21 — SIEVE ANALYSIS DIAGRAM SHOWING RANGE IN SIEVE ANALYSIS OF PIT RUN GRAVEL USED ON PRIMARY ROAD PAVING IN PALO ALTO COUNTY IN 1920.

Handling Pit-Run Gravel. In using pit-run gravel, such a system should be used, that individual loads will not be kept distinct but will be distributed through a pile of the material, and in general the larger the pile the better. In paving work pit-run gravel should not be strung along the road in small piles. The variation is likely to be so large in such a case that control of proportions will be extremely difficult. The following example from practice illustrates the beneficial effect of using pit-run gravel from a stock pile.

The pit-run gravel used on an Iowa primary road paving project in Palo Alto County was excavated by means of a slack line cableway, and

piled on the bank. It was then loaded upon industrial railway cars by means of a Barber-Greene loader, and hauled some two miles to the project. The following Table XVII from the report of the preliminary investigation of the deposit gives the physical characteristics of the gravel in place. This material is typical of the gravels covered by this bulletin.

From these tests it will be noted that the percentage of sand in the aggregate ranged from minimum of 53.2 to a maximum of 85.8 the mean value being 68.85.

During the process of construction, samples of the concrete were taken from the pavement every day, the cement removed by washing and a sieve analysis run upon the gravel. Figure 21 shows the range in comparison of the gravel as actually incorporated in the concrete during 24 days work in which time 1.86 miles of pavement were completed. It will be noted that the range in the percentage of sand was from a minimum of 66.8 to a maximum of 75.9, the mean value being 70.77.

TABLE XVII. IOWA STATE HIGHWAY COMMISSION, DEPARTMENT OF MATERIALS AND TESTS. REPORT OF GRAVEL PIT INVESTIGATION

County, Palo Alto; Township, Emmetsburg; Location, Sw Se Sec. 35; Date of Investigation: from January, 1920; Contemplated for Use on Paving; Average Haul, 1½ End Miles; Distance to R. R., 2 Miles; to Electic Power, 2 Miles; To River, On It.

Test Hole No.	Depth Top Soil Feet	Depth Stripping Feet	Depth Test Hole Feet	Max. Size Stone Ins.	Est. Percent Over Size	Percent Silt by Weight	Colorometric Test	% Pass. No. 4 Sieve	Pebbles Ret. on No. 8 Sieve			
									% Hard Stone	% Lime Stone	% Rotten Stone	% Shale
R1	4.0	4.0	10.6	2″	.....	1.13	OK	72.6	82.7	14.0	3.3	0.0
2	4.0	4.0	11.7	2″	.....	1.2	OK	60.6	77.5	12.0	7.3	3.2
3	4.0	4.0	12.1	2″	.....	1.2	OK	61.6	71.8	22.2	5.1	0.9
4	4.1	4.1	12.6	2″	.....	1.2	OK	61.2	47.1	50.7	1.3	0.9
5	2.9	2.9	10.8	2″	.....	1.5	OK	68.8	81.9	4.8	9.2	4.1
6	On bar		4.8	1½″	.....	0.4	OK	56.0	78 5	20.1	1.4	0.0
7	On bar		4.6	1″	.....	2.0	OK	67.4	64.5	28.4	7.1	0.0
8	On bar		5.0	¾″	.....	2.0	OK	68.7	75.5	23.9	0.6	0.0
A1	3.0	3.0	10.3	1½″	.....	4.8	OK	68.0	83.8	7.3	8.9	0.0
2	2.5	3.5	10.7	1½″	.....	3.2	OK	76.4	90.1	5.0	4.9	0.0
3	3.5	3.5	11.6	2″	.....	2.7	OK	64.7	87.9	8.4	3.7	0.0
B1	3.0	4.0	9.0	1½″	.....	4.4	OK	54.3	79.1	17.6	2.7	0.6
2	4.0	5.0	8.6	1″	.....	4.5	OK	72.1	67.3	28.8	3.9	0.0
3	4.0	5.0	8.8	½″	.....	4.1	OK	80.6	76.6	19.6	3.8	0.0
C1	4.0	4.5	8.6	1½″	.....	2.7	OK	53.2	67.7	29.4	2.9	0.0
2	4.0	5.0	9.0	1½″	.....	2.9	OK	65.4	79.3	14.8	5.9	0.0
3	4.2	5.2	8.7	½″	.....	3.5	OK	78.5	83.9	8.1	8.0	0.0
A2	Under water		33.0	6″	1	0.64	OK	81.1	79.8	19.5	0.3	0.4
B2	Under water		33.0	6″	1	0.4	OK	80.1	76.9	20.3	0.4	2.4
C2	Under water		33.0	6″	1	0.9	OK	85.8	85.8	12.1	1.5	0.6

Note: C4, C5 and C6 Gumbo and Clay 8′ deep.

P. J. Preston, Chief of Party.

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